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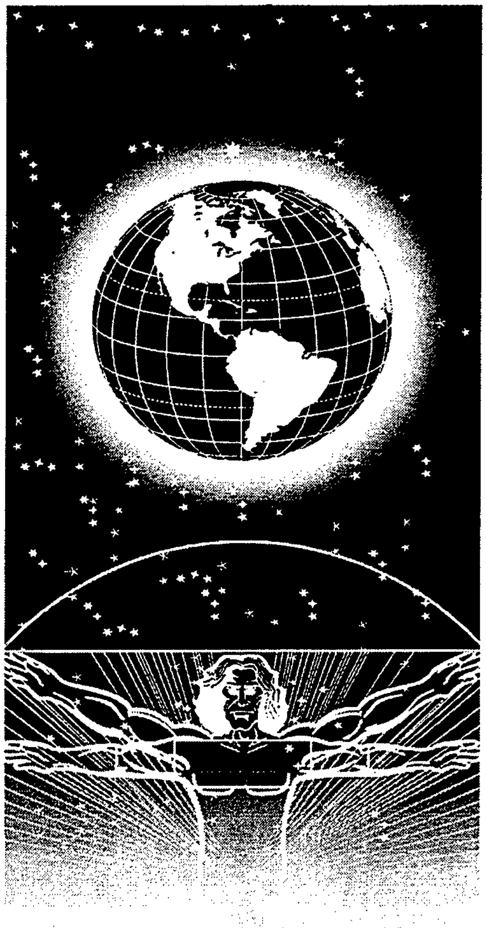

UNITED STATES AIR FORCE RESEARCH LABORATORY

SBIR Phase I Study of the Spinal Preloading Piston for the CKU-5/A Rocket Catapult

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This technical report has been reviewed and is approved for publication.

FOR THE DIRECTOR

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13. ABSTRACT (Maximum 200 words)

This Small Business Innovative Research (SBIR) Phase I effort investigated the feasibility of inserting spinal preloading technology into the current Advanced Concept Ejection Seat (ACES II). Spinal preloading may be an effective means of reducing spinal compression during the catapult phase of an emergency aircraft ejection and result in a reduction in major injuries and fatalities for the expanded aircrew population. The spinal preloading technology is based on the concept of applying a Dirac high level, short time duration impulse, then after the spine has reached its maximum compression level, applying an acceleration step function to maintain that compression level for the rest of the catapult stroke. The preliminary design is based on the addition of a short stroke Spinal Preloading Piston (SPP) between the Seat Adjustment Actuator Assembly (SAAA) and the CKU-5B/A rocket catapult in the existing ACES II ejection seat. A Gaussian optimization computer program was used to optimize the performance of the CKU-5B/A rocket catapult with the SPP. A SBIR Phase II effort was approved to continue the design, fabrication and testing of the SPP.

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SUMMARY REPORT

The purpose of this SBIR Phase I project was to study the addition of a high force level, short stroke piston to the CKU-5B/A Rocket Catapult (used on ACES-II escape system) to provide appropriate preloading of the spine of an ejectee. This preloading should result in reducing the probability of spinal injury to all ejectees, including that of the small female.

A major problem with ejection seat escape systems is the requirement for an optimum-performing catapult that expels the ejectee from the cockpit of the aircraft during an ejection event. There are specific reasons why it is preferred to have as large as possible exit velocity that does not require spinal acceleration levels that would be injurious to the spine. In this report, the history of the conceptualization and investigation of spinal preloading to reduce the probability of back injury during the catapult stroke in an ejection out of a crippled aircraft is noted. The results of tests performed by the Air Force simulating ejections under positive upward (+Gz) conditions are mentioned and the results of tests performed with live human test subjects with spinal preloading are presented.

In the first tasks undertaken in this study, we obtained data on both the CKU-5B/A cockpit installations and its internal ballistics. It was determined that with careful integration of a 1.1 inch stroke piston into the Breech of the CKU-5B/A Catapult that there would be sufficient space for it above the Seat Adjustment Actuator Assemblies (SAAA) in three of the five aircraft involved. By changing the other two SAAAs to the same drive motor of the SAAAs in these three units, there would be room in all the aircraft involved for the Spinal Preload Piston (SPP).

The detail design of the piston was undertaken once the Spinal Preload Piston location was identified. Here is a summary of the five design requirements established and incorporated into the SPP design.

1. The existing pressure input port of the CKU-5B/A would be used to initiate the SPP as well as the CKU-5B/A Catapult.

2. The qualified Housing Assembly (igniter) would be used to ignite the SPP.

3. The outside cylinder of the SPP, identified as the Breech Mount, would engage the two drive screws of the SAAA.

4. A ball lock mechanism would provide positive locking of the SPP against any negative Gz loads prior to ignition.

5. A positive stop at the end of the piston stroke must be incorporated into the SPP.

When the mechanical design of the SPP was laid out, it was possible to perform an optimization study of the internal ballistics of the SPP to obtain an end velocity between ten and twelve feet per second for the eject weight range of 300 pounds up to 451 pounds under aircraft flight conditions of level flight up to a positive Gz level of 5.05G. This study effort used fast burning ALLIANT Bullseye pistol powder and slower burning ALLIANT Reloder 19 rifle powder for the ignition and the main charges. Under the four weight and Gz combinations it was found possible using the computer model to have a velocity at the end of the SPP stroke between 10.1 feet per second and 11.0 feet per second.

With the acceleration and velocity input of the SPP identified it was possible to begin the study of the total SPP and CKU-5B/A Catapult system performance. The small pressurized area of the CKU-5B/A resulted in pressures appreciably greater than 5000 psi. At these higher pressures the burn rate of the propellant now used in the CKU-5B/A became too fast for acceptable optimization of the catapult for the small female eject weight of 300 pounds and the large male eject weight of 451 pounds at the 5.05 positive Gz escape condition. A newer propellant was used that had a more controlled burn rate at pressures above 5000 psi. With this newer propellant, assuming a burn rate slower than that for the propellant as now formulated, it was possible to optimize the system performance to give the end velocities for the 3%ile female and the 98%ile male as shown in the table below.

CONDITION	%ILE	Gz	SEPARATION VELOCITY	MAXIMUM DRI	STROKE TIME
-	-	G	FPS	-	MILLISECOND
1	3	1	48.8	15.0	121
2	3	5.05	46.4	17.3	131
3	MEAN	1	46.7	12.7	129
4	MEAN	5.05	44.7	17.4	140
5	98	1	45.1	12.4	135
6	98	5.05	43.0	17.5	147

The performance identified in this table for the three level flight (zero Gz) conditions

for which the Dynamic Response Index (DRI) never exceeds 15, with a negligible probability of back injury and with the end velocities and the stroke times provided, is a major improvement over the existing CKU-5B/A Catapult. However, the performance identified in this table for the positive Gz condition of 5.05G indicates an even greater improvement over that of the existing CKU-5B/A Catapult. Based upon this study, it is expected that a definite improvement of system performance will be demonstrated in a limited test program of twelve SPP development tests and up to twelve full catapult development tests during the SBIR Phase II follow on efforts.

Our conclusions are as follows:

1. The addition of the SPP to the CKU-5B/A Rocket Catapult will significantly reduce the injury potential to any pilot in the USAF total pilot population, especially to the small female, during any ejection under a positive Gz condition up to 5.05G (which would correspond to an acceleration level of 4.83G in the CKU-5B/A Catapult tests reported in the report AL-TR-1991-0111).

2. The SPP can be incorporated into the ACES-II Escape System with no modification to the aircraft cockpit and only minor changes to the J115103-511 and -519 Seat Adjustment Actuator Assemblies in the B-1 and F-15M aircraft. Also, there will be no changes to the J115103-513, -515, and -517 Seat Adjustment Actuator Assemblies in the F/TF-15, the A-10, and the F-16A/B aircraft.

3. The SBIR Phase II test program will provide sufficient data to warrant a full development program with sufficient time and tests to truly optimize the propellants used in the CKU-5B/A Catapult Cartridge. These tests will also optimize and demonstrate the performance of the SPP modified CKU-5B/A Catapult.

4. In conclusion, these minor changes to the CKU-5B/A Catapult would require a delta qualification test program before the SPP modified CKU-5B/A Rocket Catapult could be introduced into service use.

We recommend the following:

1. The Air Force should expedite not only the SBIR Phase II test program but also a full scale development program so the benefits expected from the introduction of this concept into service use is not delayed further.

2. It is highly recommended that the Air Force move quickly to provide spinal preloading to ejecting pilots. It has been years since Air Force personnel first recognized the potential of spinal preloading in escape system catapults to reduce

the probability of spinal injury in an ejection. Ten years ago tests on the CKU-5B/A Catapult under positive Gz conditions clearly demonstrated the severe injury potential that would result from an ejection under such positive Gz conditions. Several years have passed since the Air Force conducted drop tower tests with live subjects to demonstrate the potential of spinal preloading to greatly reduce the spinal injury potential in any ejection.

3. We recommend that the Air Force continue to lead the way in applying the Spinal Preload Piston to other escape systems, such as the NACES and the ACES-II, which should positively reduce the incidence of back injuries throughout the armed forces.

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1. INTRODUCTION

The purpose of this SBIR Phase I project was to study the addition of a high force level, short stroke piston to the CKU-5B/A Rocket Catapult (used on ACES-II escape system) to provide appropriate preloading of the spine of an ejectee. This preloading should result in reducing the probability of spinal injury to all ejectees, including that of the small female.

A major problem with ejection seat escape systems is the requirement of an optimum-performing catapult that expels the ejectee from the cockpit of the aircraft during an ejection event. A catapult separation velocity that is as high as is physiologically acceptable is preferred in all ejection conditions, but it is especially true in high speed ejections for the following reasons:

1) Rear empennage or tail clearance depends to a large extent upon the catapult separation velocity;
2) A higher catapult separation velocity will reduce nose-up tipoff at the end of catapult guidance;
3) A shorter catapult stroke time reduces the time available for loss of altitude or for the development of other adverse conditions.

Unfortunately, there are certain other requirements on the catapult performance that conflict with this desired capability of a higher catapult separation velocity. These have to do with the maximum spinal acceleration levels and rates-of-onset that the catapult produces on the ejectee.

Spinal compression under escape system catapult acceleration is a well known phenomenon. For many years the maximum spinal acceleration level that had a twenty millisecond or longer duration and the associated rate-of-onset were used to estimate the potential of spinal injury represented by a given acceleration-time history. Subsequently, the Air Force introduced the dynamic response index (DRI) as a more accurate means to evaluate the spinal injury probability represented by a spinal acceleration-time history. In this effort to evaluate the spinal injury potential of a spinal acceleration-time history, it was recognized that the spine could be effectively represented by a spring-mass-damper system with a natural frequency and a damping coefficient. A spring-mass-damper system will have a tendency to overshoot the maximum input acceleration by some factor, which in normal catapult systems is primarily determined by the rate-of-onset. In such catapult systems, a lighter weight ejectee will experience a higher maximum acceleration level and a higher rate-of-onset during the catapult stroke. This will create an appreciably higher probability of spinal injury.

A further important factor is the presence of a positive upward (eyeballs down/+Gz) acceleration of the aircraft at the time of ejection. Such positive upward aircraft acceleration tends to decrease the catapult separation velocity and, at the same time, increases the maximum spinal acceleration level that will be experienced by the ejectee. The CKU-5B/A rocket catapult designed over twenty-five years ago does not provide acceptable spinal loading during ejections under positive upward accelerations. It can be positively stated that a crewmember ejecting under a

positive upward aircraft acceleration condition greater than 4Gz with the CKU-5B/A rocket catapult has a higher probability of spinal injury than when ejecting from an aircraft in a level flight condition.

The addition of smaller female pilots into the Air Force pilot population has extended the range of the minimum ejected weight downward about 26 pounds. This reduction in the minimum ejected weight is an important consideration since the CKU-5B/A was designed and qualified for the male pilot population as it existed years ago. Even if it were possible to reduce the thrust level of the CKU-5B/A catapult section with a minimum catapult qualification program, a serious question would remain as to the effect the reduced catapult separation velocity would have on the seat performance at high airspeeds with a maximum equipped weight, large male ejectee. Verification of the acceptability of this reduced performance would require some high-speed full-system ejection tests that would be expensive and could well be unsuccessful.

Recent publications provide: 1) Advanced data on the injury potential to the spine of half-sinewave acceleration input pulses; 2) Report on the test results of the CKU-5B/A ejection seat catapult under varied acceleration levels; and 3) Report on the results of tests performed with human subjects investigating the potential for escape system performance improvement by dynamic preloading of the spine. Brinkley, Specker, and Mosher in a paper titled "Development of Acceleration Exposure Limits for Advanced Escape Systems" in the AGARD Conference Proceedings No. 472, provide low-risk, moderate-risk, and high-risk limit curves for spinal half-sinewave input pulses. Table 1 includes data taken from this paper for the low- and moderate-risk curves in the 15 to 30 millisecond pulse width time range. It is noted that the moderate-risk limit curve is based upon a spinal injury probability of about five percent (DRI = 18) and the low-risk limit curve is based upon a spinal injury probability of one-half percent (DRI =15.2). The data in this table shows an important fact: "For short time duration input pulses of 30 milliseconds or less the spinal injury potential is wholly determined by the change of velocity introduced and not by the peak acceleration level".

Table 1. Low and Moderate Risk Half-Sinewave
Exposure Limit Curve Data

LOW RISK (DRI-15.2)				MODERATE RISK (DRI-18)			
PWT (MS)	ALV (G)	VEL (FPS)	S (IN)	PWT (MS)	ALV (G)	VEL (FPS)	S (IN)
15	42	12.9	1.16	15	51	15.7	1.41
20	31	12.7	1.53	20	38	15.6	1.87
25	25	12.8	1.92	25	31	15.7	2.31
30	21	12.9	2.33	30	26	15.7	2.82

PWT = Pulse width time, ALV = Acceleration Limit Value, VEL = Velocity, S = Displacement

Brinkley and Toler's report (AL-TR-1991-0111) titled "Evaluation of the CKU-5B/A Ejection Seat Catapults Under Varied Acceleration Levels" had four conclusions and six recommendations. The fourth conclusion was as follows: "The probability of spinal injury increased to alarming rates as the

impressed acceleration was increased". The first recommendation was "a study of operational aircraft accidents should be conducted to evaluate the probability of ejection under impressed acceleration." The second was "if the probability of ejection under impressed acceleration is found to be high enough to be a significant concern to aircraft operators, the feasibility of redesigning the CKU-5B/A rocket catapult should be evaluated." A primary goal of this SBIR effort was to develop a separate means of preloading the spine of the ejectee so that acceptable performance of the CKU-5B/A rocket catapult would result without major modification of its ballistics.

In Strzelecki's report he surmised: "The theory that dynamic preloading of the spine could reduce injury potential was demonstrated with human subjects in the laboratory. The reduced DRI to be expected from a test with dynamic preload versus one without was corroborated by physical measurements." [1] He also stated that "a potential limit on the increase in acceleration tolerance, made possible by dynamic preload, is the capacity of the neck to sustain the increased loading as the dynamic preload demonstrated there had no beneficial effect on head acceleration." Table 2 includes data from Table 3 of AL/CF-TR-1993-0167 and indicates both the reduction in DRI and the increased velocity change that the spinal preloading active in Cell B provided in this test effort. Most importantly, while the average head acceleration only decreased about 1.5 percent with spinal preloading (Table 6 of AL/CF-TR-1993-0167) for the same acceleration level the average velocity change increased 13.7 percent. This indicates that spinal preloading to the CKU-5B/A Ejection Seat Catapult can increase ejection acceleration from about 42 to 48 feet per second with a slight reduction in head acceleration and a significant (about 22 percent) reduction in DRI. Although the conditions represented level flight, a similar or greater DRI reduction should be realized for positive Gz ejections.

During a 1993 SBIR Phase I study of the Spinal Preload Catapult (Contract No. F41624-93-C-6010), USAF ejection data for the years 1981 through 1992 was evaluated to determine the worst-case ejection conditions of eject weight, positive Gz aircraft acceleration, and temperature. The results of this evaluation were included in the Final Report of that SBIR Phase I effort dated 4 January 1994. The positive Gz data showed a Mean of 1.5G and a Standard Deviation of 1.42G for the

Table 2. Summary of Results for Characteristic Test

CELL	NOMINAL PEAK G	DRI	VELOCITY CHANGE IN 0.183 SEC.	DISPLACEMENT IN 0.183 SEC.
A	6	7.4	248.5 in/sec	21.5 inch
B	8	8.1	344.9 in/sec	33.6 inch
C	8	10.4	303.4 in/sec	28.3 inch

10G Preload

1 Strzelecki, <u>An Investigation With Human Subjects into the Potential for Dynamic Preloading of the Spinal Column to Improve Escape System Performance</u>, (AL/CF-TR-1993-0167).

sample of 132 ejection events. In this study, a level flight condition with zero upward seat acceleration was considered a Gz equal to 1G. This study gave a 3 Sigma maximum Gz value of 5.76 (seat upward acceleration of 4.76G), which was a very conservative value, and indicated an ejection under 5.76 Gz will only occur once in about 770 ejections.

A more careful study of this Air Force data was conducted for this SBIR Phase I project in which the level flight condition was used as a zero seat acceleration. Also, those ejections which had low speeds (after a flame out for example) at the time of ejection were considered as zero seat acceleration conditions even if an earlier high acceleration condition had existed and possibly had caused the emergency. This study indicated that the Mean seat acceleration value was 0.224 and the Standard Deviation. Sigma, was 1.006. The best estimate of the Mean plus 3 Sigma level then was 3.24G which indicates that in only one out of 770 ejections would experience this positive 3.24G seat acceleration level or greater. It also indicates that a positive upward seat acceleration level of 4.05G (Mean plus 3.755 Sigma) or greater would only occur in about one out of 10,000 ejections. Based upon the results of this more accurate study, a seat upward acceleration level of 4.05 was recommended to the Air Force in the Kickoff Meeting held on 19 May 1998. This acceleration level will provide the worst-case ejection condition for the determination of the modifications to the ballistic charges that would be used in the CKU-5B/A catapult to achieve the desired objectives.

The probability of spinal injury to all ejectees would be within the accepted moderate risk level (DRI of 18) of about five percent for seat positive upward acceleration levels of 4.05 or less. Reliable timing of the ignition of both the Spinal Preloading Piston (SPP) and the CKU-5B/A catapult section, as well as the proper modification of the propellants used in the catapult, were recognized as critical ingredients to the successful achievement of this objective.

Note: A seat upward acceleration of zero in a level flight condition corresponds to an aircraft G meter reading of 1G. Nevertheless, the seat acceleration as used in this report is always the actual seat and ejectee Z-axis acceleration.

2. TASKS DEFINITION

This SBIR Phase I Study of the Spinal Preloading Piston for the CKU-5B/A Rocket Catapult was performed in seven tasks defined as follows:

Task 1.	Data for CKU-5B/A Rocket Catapult Installations.
Task 2.	Data for CKU-5B/A Catapult Internal Ballistics.
Task 3.	Preliminary Spinal Preload Piston Concepts Study.
Task 4.	Detailed Spinal Preload Piston Concepts Study.
Task 5.	Ejection Performance Study.
Task 6.	Preliminary Design of Selected Spinal Preload Piston Concept.
Task 7.	Documentation and Reporting.

3. TASK EFFORTS

3.1 Task 1 Efforts

The Air Force provided drawings to LME showing the area of the cockpit where the ACES-II seat mounts to the aft bulkhead via the guide rails and the seat height adjustment actuator. One-quarter scale drawings of the single place and dual place F-16 cockpits and an 8.5 by 11 inch drawing of the F-15 cockpit were also supplied to LME. The Technical Monitor provided a used seat height adjustment actuator. These items were important for use in the Task 3 and Task 4 Spinal Preload Piston Concepts studies. It also became apparent that similar information/data for the back of the ACES-II seat would be helpful to this study effort.

Mr. Hal Watson of the Universal Propulsion Company (UPCo) supplied an assembly drawing of the CKU-5B/A rocket catapult manufactured by UPCo. This drawing, NAVSEA Drawing Number 6610113, provided complete outside dimensional data on the CKU-5B/A Rocket Catapult. Other drawings supplied by UPCo gave important information on the internal dimensions and on the arrangement of the components inside the CKU-5B/A Catapult. Most important to this project were the definition of the small pressurized area and the limited empty volume of this catapult. Compared to other catapults, the small pressurized area of the CKU-5B/A Catapult has to have much higher pressures to provide the necessary accelerations to the ejectee and the ACES-II seat.

Although not originally planned, LME visited Shaw Air Force Base to study and photograph the back of the ACES-II ejection seat and the cockpit of an F-16 single seat aircraft. The positive support of Master Sergeant Laney during this visit was of tremendous help and resulted in a much clearer understanding of the problems that would be faced in the Spinal Preload Piston installation in an aircraft. The photographs taken of the guide rails and the Seat Height Adjustment Actuator gave the first indication that mounting the SPP directly beneath the CKU-5B/A Rocket Catapult was a distinct possibility.

Mr. Fred Rinke, at the request of the Technical Monitor, supplied a Seat Adjustment Actuator Assembly to LME. This actuator gave confirmation that, even with the actuator adjusted

full down, there was room above the drive motor of that model (115103-117) actuator for the SPP to be located directly under the CKU-5B/A Rocket Catapult. Subsequently, via a contact at Weber Aircraft, LME obtained the Douglas Aircraft Company Drawing J115103, ACTUATOR ASSY - ADJUSTMENT, SEAT, which also verified that for all aircraft other than the F-15M and the B1 there was sufficient space for the SPP above the actuator drive motor. Although not defined in this drawing, it appears that two separate vendors supply drive motors for the J115103 actuator and that those manufactured by the Skurka Engineering Company are shorter. Thus, it is reasonable to believe that the -519 model in the F-15M and the -511 model in the B1 can be modified to have the reduced height needed to clear the SPP.

3.2 Task 2 Efforts

INTERNAL BALLISTICS DATA REQUESTED

The upward velocity imparted to the seat and the seat occupant by the spinal preload piston (SPP) will drastically affect the CKU-5B/A catapult. The design goal for the SPP was to have it impart a velocity between 10 and 12 feet per second into the seat mass and the effective occupant mass, which is assumed to be about 50 percent of the total equipped occupant mass for the 1.125 inch stroke of the SPP. As time passes after the SPP stroke time, the CKU-5B/A catapult will pick up the total occupant mass. To predict the total catapult performance after the SPP has been added, internal ballistics data for the existing CKU-5B/A catapult was required. This data included the heat energy, heat of explosion provided by the burning of the propellant, and at least two of the following values for the gasses produced by the burning of the propellant were required for the calculation of the temperature of the gasses throughout the catapult stroke:

(1) Gas Molecular Weight in Moles (W)
(2) Gas Constant (R)
(3) Ratio of Specific Heats (k)
(4) Specific Heat at Constant Volume (c_v)
(5) Specific Heat at Constant Pressure (c_p)

The propellant density, grain dimensions, and burn rate data in the low pressure range up to 5000 psi and in the high pressure range above 5000 psi are required for calculation of the gas generation rate at the instantaneous pressure levels. The CKU-5B/A catapult initial ignition pressure and timing, its initial free volume, and its pressurized area are required for calculation of the thrust-versus-time characteristics throughout the catapult stroke.

INTERNAL BALLISTICS DATA OBTAINED.

The Air Force Technical Monitor was able to provide LME with the internal ballistics data for the Navy propellant and catapult dimensional data for the CKU-5B/A catapult produced at the NOS Indian Head, MD facility. Ray Raetzel, UPCo., provided this data to LME for the CKU-5B/A catapult produced by that company in Phoenix, AZ. These supplied internal ballistics data are provided in Figures 1.

Mr. Raetzel also provided some actual test curves of cartridge pressure, catapult thrust, and catapult acceleration versus time for firings at -65°F and 165°F. This information provided important data relative to the timing of the firing of the igniter and the release of the negative Gz lock of the catapult.

At a much later time, after the catapult performance studies of Task 5 had been undertaken, data on an advanced UPCo propellant which exhibits a constant pressure exponent through a much higher pressure range was obtained from UPCo. The burn rate of this propellant as presently being manufactured is 0.75 inch per second at a pressure of 1000 pounds per square inch (see Figure 2) which was found to be too fast for the CKU-5B/A Catapult. In discussions with Mr. Hal Watson and Dr. Jim Baker at UPCo it was determined that if certain fillers and coolant were added to this propellant its burn rate could be reduced. Subsequent Task 5 studies showed that a burn rate of 0.35 inch per second at a pressure of 1000 pounds per square inch with the same pressure exponent of 0.7 would be about optimum for the CKU-5B/A Catapult after the SPP had been added to it. This propellant has been selected for use in future efforts on this project.

3.3 Task 3 Efforts

In our proposal, LME identified five spinal preload piston (SPP) concepts that would be studied to evaluate their applicability to the ACES II escape system.

CONCEPT (1)

Incorporate one or two pistons into the Seat Adjustment Actuator Assembly (SAAA) to accelerate the total escape system mass, including the SAAA, upward a very short distance with a high acceleration level. This concept, if acceptable, requires only minor modifications to the internal ballistics of the CKU-5B/A catapult.

EVALUATION

Figure 3 is a photograph of the SAAA of an F-16 single seat aircraft at Shaw AFB and the CKU-5B/A rocket catapult mounted in the cockpit. Because the open space between the bulkhead mounted support brackets and the guide

NAVAL Ordnance Station Indian Head (NOS) PROPELLANT DATA

1. HEAT OF EXPLOSION: H = 1230 cal/gm = 2214 BTU/lb
2. FLAME TEMPERATURE: T_f = 4590 °F = 5050 °R
3. RATIO OF SPECIFIC HEATS: k = 1.22
4. SPECIFIC HEATS:
   CONSTANT VOLUME: c_v = 483.41 / (1.8 * 778.26) = 0.345 BTU / (lb_m * °F)
   CONSTANT PRESSURE: c_p = k * c_v = 0.421 BTU / (lb_m * °F)
5. GAS CONSTANT: R = c_v * (1 - k) * 778.26
   = 59.07 lb_f * ft / (lb_m * °F)
6. GAS MOLECULAR WEIGHT: W = 1545.4 / R = 24.6 MOLES
7. DENSITY: = 1.67 gm / cc = 0.0603 lb_m / in^3
8. BURN RATES:
   @ 1000 psi: r_b = 0.622 in / sec, n = 0.45
   @ 7500 psi: r_b = 2.001 in / sec, n = 1.16
9. GRAIN DIMENSIONS:
   ID = 0.264 in, OD = 0.727 in, LENGTH = 4.95 in
10. PRESSURIZED AREA: A = 0.7854 in^2
11. INITIAL FREE VOLUME: V_0 = 19.93 IN^3
12. IGNITION PRESSURE: p_0 = 600 psi @ 0.005 sec

BURN RATE CROSSOVER PRESSURE

$$2.009 * (p / 7500)^{1.16} = 0.622 * (p / 1000)^{0.45}$$
$$2.009 * (p)^{1.16} / 31{,}266 = 0.622 * (p)^{0.45} / 22.387$$
$$p^{0.71} = 0.622 * 31{,}266 / (2.009 * 22.387) = 432.4$$
$$p = 432.4^{1.4085} = 5158 \text{ psi}$$

UNIVERSAL PROPULSION PROPELLANT DATA

1. HEAT OF EXPLOSION: H = 1235 cal/gm = 2223 BTU/lb
2. FLAME TEMPERATURE: T_f = 4547 °F = 5007 °R
3. GAS MOLECULAR WEIGHT: W = 24.6 MOLES
4. GAS CONSTANT: R = 1545.4 / W = 62.82 lb_f * ft / (lb_m * °F)
5. RATIO OF SPECIFIC HEATS: k = 1.22
6. SPECIFIC HEATS:
   CONSTANT VOLUME: c_v = R / [(k-1) * 778.26]
   = 0.367 BTU / (lb_m * °F)
   CONSTANT PRESSURE: c_p = k * c_v = 0.448 BTU / (lb_m * °F)
7. DENSITY: = 1.67 gm / cc = 0.0603 lb_m / in^3
8. BURN RATES:
   @ 1000 psi: r_b = 0.70 in / sec, n = 0.39
   @ 7500 psi: r_b = 2.20 in / sec, n = 0.90
9. GRAIN DIMENSIONS:
   ID = 0.264 in, OD = 0.727 in, LENGTH = 4.95 in
10. PRESSURIZED AREA: A = 0.789 in^2
11. INITIAL FREE VOLUME: V_0 = 13.02 IN^3
12. IGNITION PRESSURE: p_0 = 600 psi @ 0.005 sec

BURN RATE CROSSOVER PRESSURE

$$2.20 * (p / 7500)^{0.90} = 0.70 * (p / 1000)^{0.39}$$
$$2.20 * (p)^{0.90} / 3073 = 0.70 * (p)^{0.39} / 14.79$$
$$p^{0.51} = 0.70 * 3073 / (2.20 * 14.79) = 66.11$$
$$p = 66.11^{1.961} = 3711$$

Figure 1.

UNIVERSAL PROPULSION 6002 (PVC/KP) PROPELLANT DATA

1. HEAT OF EXPLOSION: H = 1020 cal/gm = 1836 BTU/lb
2. FLAME TEMPERATURE: T_f = 1490 °F = 4950 °R
3. GAS MOLECULAR WEIGHT: W = 43.5 MOLES
4. GAS CONSTANT: R = 1545.4 / W = 35.52 lb_f * ft / (lb_m * °F)
5. RATIO OF SPECIFIC HEATS: k = 1.2
6. SPECIFIC HEATS:
   CONSTANT VOLUME: c_v = R / [(k-1) * 778.26] = 0.228 BTU / (lb_m * °F)
   CONSTANT PRESSURE: c_p = k * c_v = 0.274 BTU / (lb_m * °F)
7. DENSITY: = 2.00 gm / cc = 0.0722 lb_m / in^3
8. BURN RATES:
   @ 1000 psi: r_b = 0.75 in / sec, n = 0.70
   @ 7500 psi: r_b = 3.07 in / sec, n = 0.70
9. GRAIN DIMENSIONS:
   ID = TBD in, OD = 0.727 in, LENGTH = TBD in
10. PRESSURIZED AREA: A = 0.789 in^2
11. INITIAL FREE VOLUME: V_0 = 13.02 IN^3
12. IGNITION PRESSURE: p_0 = 600 psi @ 0.005 sec
13. IGNITION TEMPERATURE: T_0 = 1060°F

Figure 2.

rails for the ACES II seat is occupied by the seat structure supporting the bottom rollers that engage the guide rails, the SPP components acting between the SAAA and the aircraft structure must be contained within these bulkhead mounted support brackets. The practical size of each of the two piston and cylinder mechanisms for an SPP is in the order of one and one-half inch outside diameter and over one inch long. It is clear from Figure 3 that it was not practical to incorporate two such SPP piston and cylinder assemblies into the SAAA that could act to accelerate the SAAA, the CKU-5B/A rocket catapult, the seat, and the seat occupant upward about one and one-eighth inch.

CONCEPT (2)

If possible a short stroke piston would be mounted completely within the space between the two drive screws of the SAAA (without encroaching on the CKU-5B/A rocket catapult mechanically). This would accelerate the escape system mass of the seat, the seat occupant, and the CKU-5B/A rocket catapult upward in a very short time and with a high acceleration level. This concept, if acceptable, would require only minor modifications to the internal ballistics of the CKU-5B/A catapult but no mechanical or dimensional changes to it.

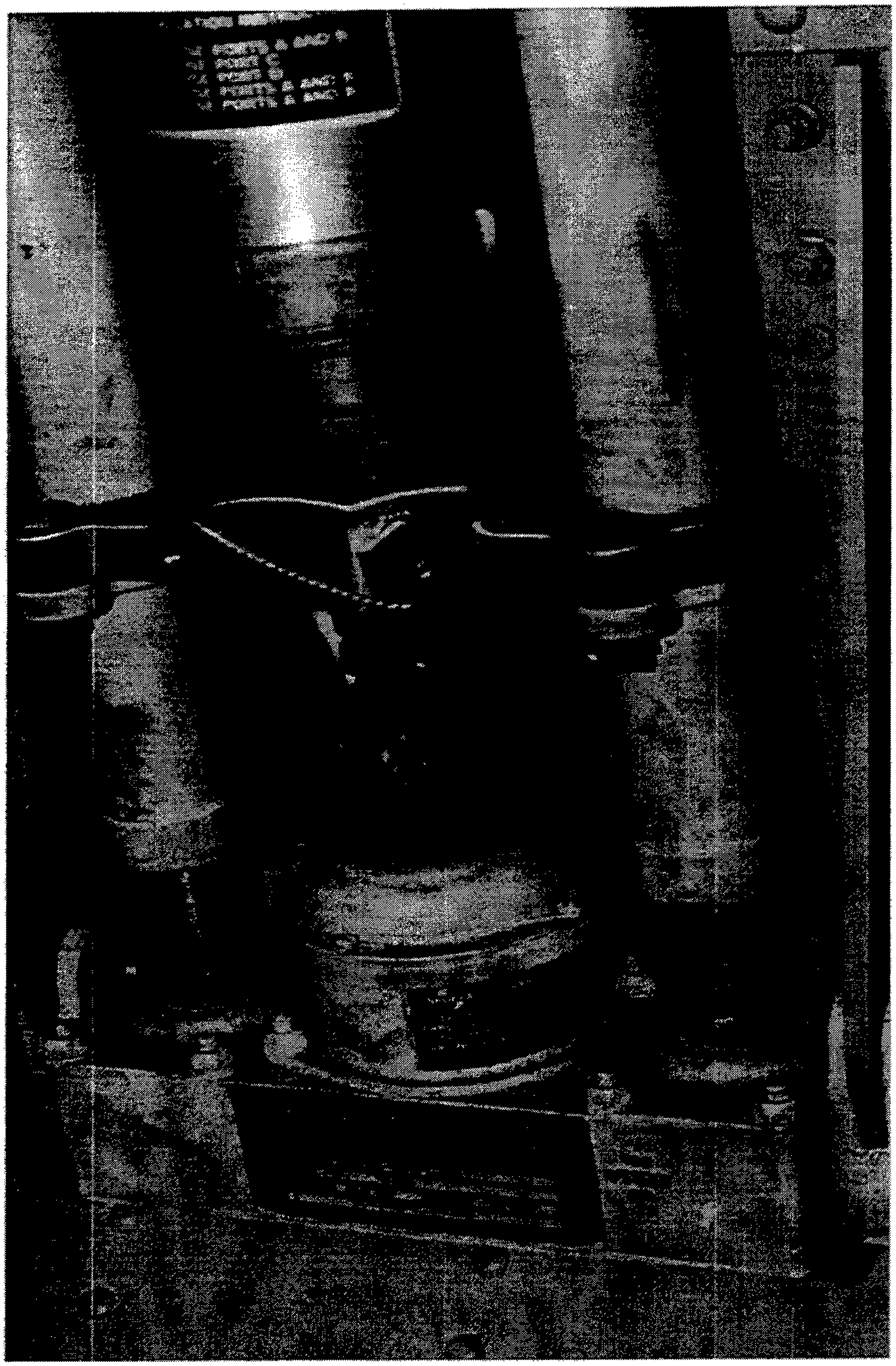

Figure 3.

EVALUATION

Figures 4 and 5 are photographs of the SAAA in the F-16 single seat aircraft at Shaw AFB and the CKU-5B/A rocket catapult mounted in the cockpit. The photos provide a view of a measuring tape to give some idea of the open space beneath the CKU-5B/A rocket catapult. Figure 4 indicates that the SAAA was adjusted about one and one-half inch up from its maximum down position. Figure 5 indicates that the distance from the top of the housing of the SAAA drive motor to the bottom of the breech of the CKU-5B/A rocket catapult was a little less than two and three-quarter inches. More than one inch spacing would be available for the SPP when the ACES II seat is adjusted full down. Further review of the SAAA Drawing J115103-517 revealed that the minimum space, with the seat adjusted full down, between the top of the housing of the drive motor of the SAAA and the support surface of the Breech of the CKU-5B/A Rocket Catapult was slightly more than 1.4 inch. This would be sufficient for the SPP if it were integrated into the CKU-5B/A Breech.

CONCEPT (3)

If and when the SAAA is incorporated into the ACES II seat structure, the space directly beneath the CKU-5B/A rocket catapult would then become available for a piston that would provide a high acceleration level for a short distance to the total escape system mass. Upon learning that Safety Equipment International (SEI) is working on this ACES II seat structure concept, we decided that this approach to the SPP was a logical one to study.

EVALUATION

Safety Equipment International (SEI) is working on the development of an ACES II seat bucket structure that will provide both vertical and fore and aft adjustment. This will allow the center-of-gravity (cg) for the ejected seat mass envelope for the specified range of dimensions and weights for the small female to the large male to be reasonably defined. Based on this envelope, the desired vertical location of the ACES II rocket thrust vector will provide at least five inches of vertical space between the cockpit floor and the bottom surface of the Breech of the CKU-5B/A rocket catapult. This third concept can easily incorporate concept (2) when the SEI project has reached a successful conclusion and is qualified as an advanced replacement for the existing ACES II escape system.

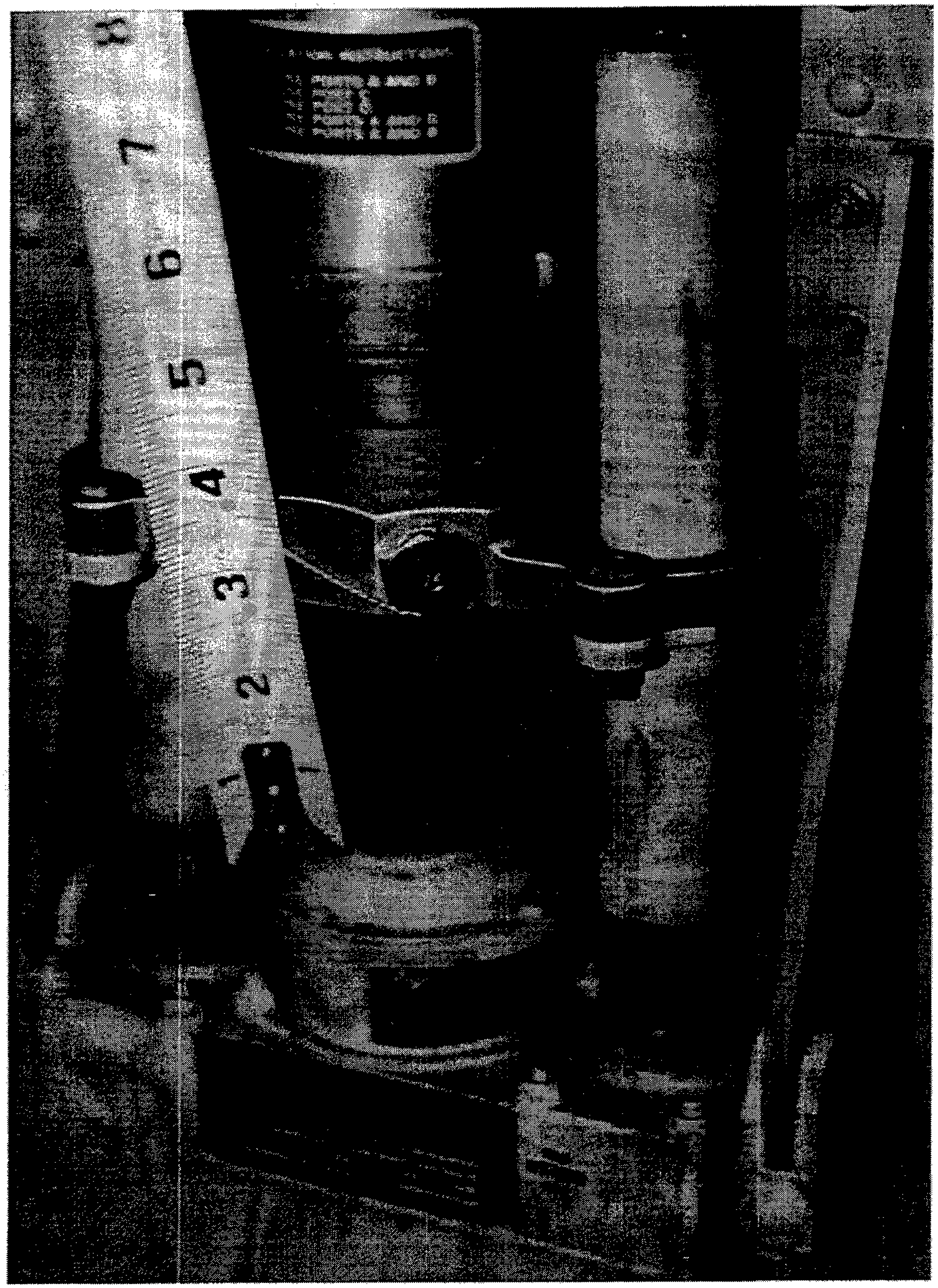

Figure 4.

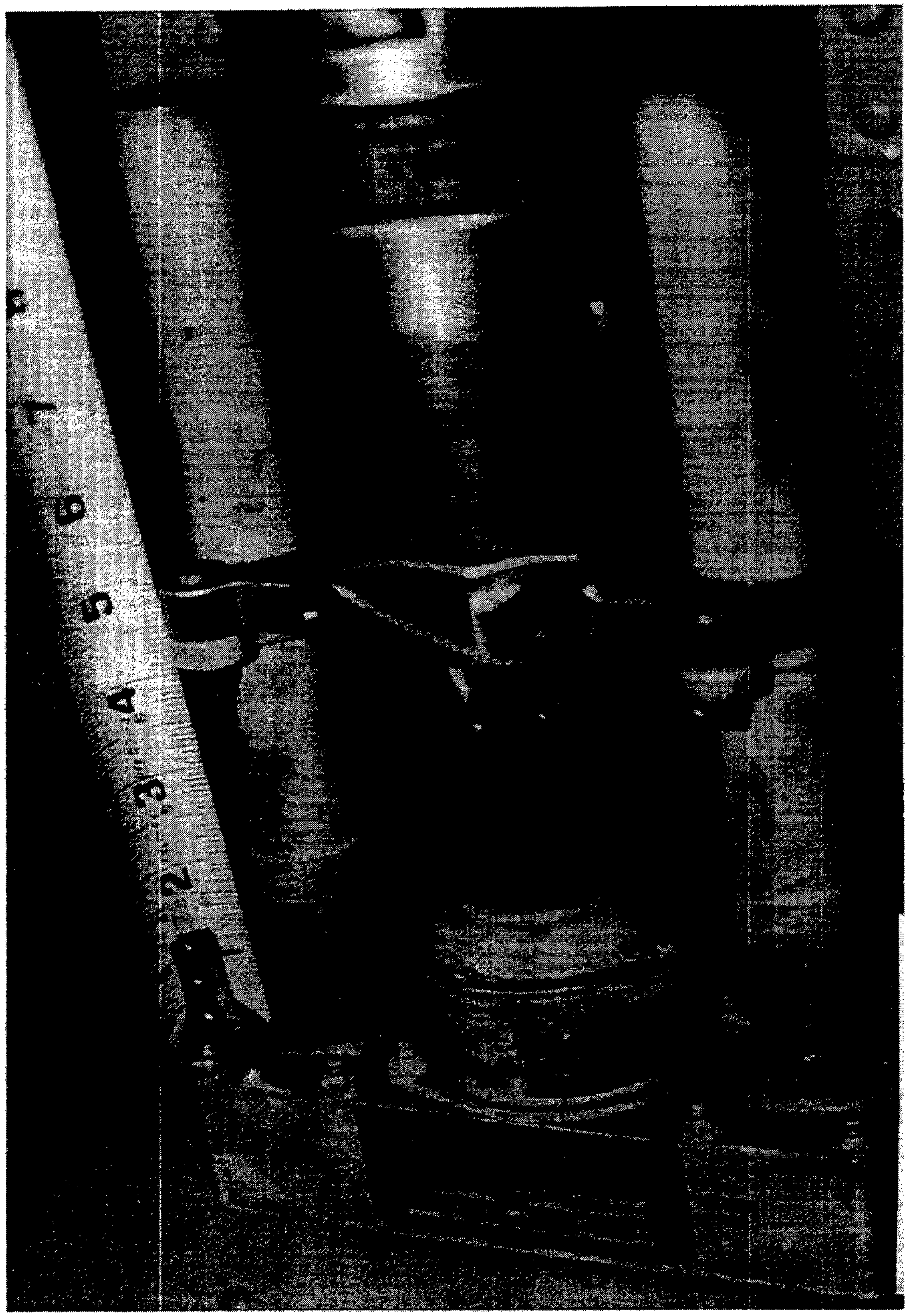

Figure 5.

CONCEPT (4)

Mount a short stroke piston between the SAAA and the CKU-5B/A catapult that would accelerate the escape system mass of the seat, the seat occupant, and the CKU-5B/A rocket catapult upward a very short distance with a high acceleration level. This concept would result in a shortened envelope for the CKU-5B/A rocket catapult and would require several modifications to the mechanical design of the CKU-5B/A rocket catapult as well as to its internal ballistics.

EVALUATION

As was determined in the study of Concept (2), slightly more than 1.4 inch vertical spacing would be available for the SPP when the ACES II seat is adjusted full down. Thus the space available for the SAAA beneath the CKU-5B/A Rocket Catapult should be sufficient for its integration into the Breech of the CKU-5B/A Rocket Catapult without any shortening of the catapult stroke or of the rocket grain.

CONCEPT (5)

Mount a short stroke piston between the CKU-5B/A rocket catapult and the ACES II seat that would accelerate the escape system mass of the seat and the seat occupant upward a very short distance with a high acceleration level. This concept would also result in a shortened envelope for the CKU-5B/A rocket catapult and would require several modifications to the mechanical design of the CKU-5B/A rocket catapult as well as to its internal ballistics.

EVALUATION

There are several important negative considerations to this concept so it should not be seriously considered. First, there would be as much as a two inch loss in catapult stroke and a similar reduction in the volume available for the rocket grain. Second, as the SPP strokes one and one-eighth inch the rocket nozzle would be moved downward relative to the ACES II seat by that same distance. To maintain the proper thrust vector to center-of-gravity (cg) alignment the rocket nozzle angle would then need to be changed to give a more vertical thrustline angle. Probably the most important consideration is the need for redundant pressure lines to transmit the initiation signal up to the SPP. The SPP must be able to disconnect in an ejection and must be somehow disconnected to remove the ACES II seat from the aircraft.

TASK 3 CONCLUSIONS.

Concept (2) is given the highest priority rating index for the follow-on design efforts in Task 4, "Detailed Spinal Preload Piston Concepts Study." LME received a copy of the Douglas Aircraft Company Drawing J115103 of the Seat Adjustment Actuator Assembly through a contact at the Weber Aircraft Company. This drawing shows that the -513 in the F/TF-15 and the -515 in the A-10 have the same drive motor housing as the -517 in the F-16A/B. Only the -511 and the -519 actuators in the B-1 and the F-15M aircraft, which have a higher drive motor housing, would not have sufficient space for the SPP. Since the SPP would fit in the B-1 and the F-15M aircraft if the drive motors presently in the -511 (B-1) and -519 (F-15M) actuators are replaced with drive motors similar to those in the -513, -515, and -517 actuators, the other four concepts were not considered further.

3.4 Task 4 Efforts

The Task 4 detailed SPP concepts study efforts were significantly reduced in scope since only the second concept considered in Task 3 needed to be studied further. The planned Task 6 preliminary design of this selected concept was actually performed as Task 4 so a better definition of the SPP would be used in the Task 5 performance studies. It was obvious that if the SPP was to be mounted between the SAAA and the CKU-5B/A Rocket Catapult, it would be necessary to integrate it into the Breech of that device. Several requirements were established for this concept which were believed to be essential to an optimum SPP design. These requirements included the following:

1. The existing pressure input port of the CKU-5B/A Breech would be used to initiate both the CKU-5B/A Catapult and the SPP to ensure the best possible timing of these two events.

2. The qualified Housing Assembly (Igniter) of the CKU-5B/A Rocket Catapult would also be used as the Igniter in the SPP to assure reliable initiation of the SPP with a new output charge (0.08 gram Alliant Bullseye pistol powder).

3. The outside cylinder of the SPP, identified as the Breech Mount, would mount to the two drive screws of the SAAA.

4. A ball lock mechanism incorporating six each 0.1875 inch diameter balls would provide positive locking of the outside cylinder (Breech Mount) to the inner piston (Breech) against any negative Gz loads acting to raise the seat upward away from the cockpit floor. This ball lock mechanism will immediately unlock when the internal pressure of the SPP becomes 100 psi or greater.

5. A means for providing a positive stop at the end of the piston stroke to assure that the internal gas pressure is maintained throughout the CKU-5B/A Catapult stroke. To ensure that this stop will not be overcome, energy absorbing means shall be provided for a short distance of one-eighth inch or less.

The design of the SPP, which provides the above listed features, was accomplished. The stroke provided is one and one-sixteenth inch. The SPP Assembly (Drawing Number 11041400) consists of five assorted O-rings, four bolts, two flat head screws, the igniter assembly, the main propellant charge (1.4 grams Alliant Reloder 19 rifle powder), two shear pins, six ball bearings, and the following five machined parts.

	Name	Drawing No.
1.	BREECH	11041401
2.	BREECH MOUNT	11041402
3.	BALL LOCK HOUSING	11041403
4.	BALL RELEASE	11041404
5.	ENERGY ABSORBER	11041405

Copies of the Assembly drawing and these five drawings are provided in Appendix A.

3.5 Task 5 Efforts

The Task 5 Ejection Performance Study was carried out in two stages. In the first stage an attempt was made to optimize the performance of the SPP for the Min./Max. ejection weights at the seat acceleration levels of 0G and 4.05G. In the second stage an attempt was made to optimize the CKU-5B/A Catapult when the SPP, performing as determined in the first stage, had been incorporated into it.

FIRST STAGE STUDIES

A relatively simple computer program was written that modeled a closed chamber thrust generator powered by two different charges. The first charge, as represented in the model, consisted of small discs that burned on all exposed surfaces. The second charge consisted of small cylindrical single perforation grains, which were inhibited from burning on the outside cylindrical surface to provide a rapidly increasing burning surface area. Different values for the burning rate as a function of pressure, the flame temperature, the gas constants for the products of combustion, and the density of the unburned propellant could be input for these two charges. The $BKNO_3$ (Boron Potassium Nitrate) of the standard igniter in the CKU-5B/A catapult is replaced by ALLIANT (formerly HERCULES) Bullseye pistol powder which is extremely fast burning and rapidly pressurizes the initial empty volume of the SPP to over 1500 psi in a few milliseconds. This Bullseye powder was modeled by the first charge discs. The second charge modeled ALLIANT Reloder19 rifle powder which is a single perforation, outside surface inhibited grain that is relatively slow burning. The desired goal of this first stage study was to determine the weight of the Bullseye powder in the igniter housing and the weight of the Reloder19 in the SPP inside volume that would give the desired velocity at the end of the 1.125 inch piston stroke. Since the piston stroke was

over in 22 milliseconds, the model neglected all heat loss through the cylinder wall. By varying the total weight of and the weight ratio between these two charges relatively consistent performance of the SPP for the max./min eject weights and for the 0G and the 4.05G seat acceleration levels was achieved. The computed performance is listed in Table 3.

Table 3. Final Spinal Preload Piston Performance Data

CONDITION	%ILE	SEAT ACCELERATION	END VELOCITY	STROKE TIME
-	-	G	FPS	MILLISECONDS
1	3	0	11.0	19.3
2	3	4.05	11.0	20.2
3	98	0	10.1	21.1
4	98	4.05	10.1	22.0

SECOND STAGE STUDIES

Over 15 years ago, Dr. C.D. Kylstra wrote a Gaussian optimization computer program that modeled a catapult. This program modeled both pellets and granules of $BKNO_3$ in the igniter and a single perforation inside, and ends burning propellant grain. To optimize the performance of the CKU-5B/A Catapult when the SPP was integrated into it, some major changes were carried out in the catapult model in this program. The small pressurized area of this CKU-5B/A Catapult (0.785 square inch) requires pressures appreciably greater than 5000 psi so that acceptable thrust levels can be generated. Since the slope of the burning rate versus pressure function for most propellants increases greatly for pressures above 5000 psi, the catapult model was changed to allow a burn rate and pressure exponent for the burn rate at 7500 psi as well as at 1000 psi to be input to the model. Also, the spherical model of the $BKNO_3$ granules was removed from the igniter and altered to allow two new charges in a separate housing to be modeled. One of these two new charges modeled represented thin strips of propellant that would burn relatively quickly with a nearly constant burning surface area. The other new charge modeled could be either a single perforation inside burning, outside inhibited grain or a seven perforation inside burning, outside inhibited grain. A later modification allowed a tapered inside diameter propellant grain to be modeled. This approach allowed the burning surface area to decrease as the propellant grain neared burnout where the catapult pressure was quite high and the propellant burn rate at that high pressure had increased to an excessive value.

The initial studies concentrated on using the propellant that was already qualified in the CKU-5B/A. It was quickly learned that to keep the DRI level at a value of 18 for the heavy male ejecting under the 4.05G upward seat acceleration level for a moderate risk of back injury, the performance for the other three conditions of the small female under 4.05G and 0G and the large male under 0G upward seat acceleration was only marginally acceptable. This was primarily true

because of the extremely high burn rate in the high pressure range above 5000 psi. The best performance achieved using this propellant was with a 4° tapered grain, which is provided in Table 4.

Table 4. Best SPP/Catapult System Performance Data With Existing CKU-5B/A Propellant

CONDITION	%ILE	SEAT ACCELERATION	SEPARATION VELOCITY	MAXIMUM DRI	STROKE TIME
-	-	G	FPS	-	MILLISECOND
1	3	0	46.1	16.1	121
2	3	4.05	42.3	17.4	131
3	98	0	42.4	12.7	132
4	98	4.05	39.0	17.9	146

After sharing my concerns about the extreme high burn rates at pressures above 5000 psi with Mr. Hal Watson of the Universal Propulsion Company, he offered to supply a qualified propellant (UPCo number 6002 PVC/KP propellant) that had a burn rate versus pressure function with a near constant pressure exponent. The data on this propellant showed a high burn rate of 0.75 inch per second at 1000 psi and a pressure exponent of 0.70. With this rapid burn rate at low pressures it was evident that the internal diameter of the Catapult Inner Tube and thus the Cartridge Housing, was too small. There was not sufficient room to get a grain with the minimum required burn distance inside the cartridge. After expressing disappointment over the high burn rate of this propellant to Mr. Watson, he and Dr. Jim Baker, a propellant development expert at UPCo., said this propellant could be modified by adding coolants and binders to give almost any burn rate desired. They suggested that a desired burn rate at 1000 psi should be determined using the computer model, and they would consider what would be needed to obtain that burn rate.

Based on the previous runs, we decided to try a burn rate of 0.35 inch per second at 1000 psi with the same pressure exponent of 0.70 (identified as PVC/KP-1). Based on the results obtained, a new lower or higher burn rate would be evaluated. The tapered grain was evaluated first. It was soon evident that the selected burn rate of 0.35 inch per second at 1000 psi with a pressure exponent of 0.70 was very near optimum such that a grain, without any taper required, could provide excellent performance results for the four conditions being considered. After only a few attempts at optimization, the following charge sizes provided the best performance as listed in Table 5. Also included in this table is the computed performance of the catapult system with the SPP added for the mean ejected weight of 376 pounds and the same igniter and propellant charges.

Table 5. Best SPP/Catapult System Performance Data With PVC/KP-1 Propellant

Igniter Charge: 4.8 grams, Type II-A $BKNO_3$ BI-CONVEX pellets (MIL-P-46994).
Fast Burn Charge: 0.24 gram, 0.022 inch thick PVC/KP-1 strips.
Moderate Burn Charge: 0.49 gram, seven perforations, 0.33 inch OD PVC/KP-1 pellets.
Slow Burn Charge: 5.1 inch long, 0.367 inch ID, 0.727 inch OD (52 grams), PVC/KP-1 grain.

CONDITION	%ILE	SEAT ACCELERATION	SEPARATION VELOCITY	MAXIMUM DRI	STROKE TIME
-	-	G	FPS	-	MILLISECOND
1	3	0	50.4	16.7	117
2	3	4.05	47.4	18.0	126
3	MEAN	0	47.9	14.4	124
4	MEAN	4.05	44.8	17.5	135
5	98	0	46.0	13.0	131
6	98	4.05	42.6	16.9	143

When these results were discussed with Dr. Baker he expressed some concern as to whether it would be possible in a short term program with limited funding to provide an exact burn rate value. In addition, the manufacture of seven perforation grains, as required for the moderate burn charge, were considered impractical. Further studies were made on this PVC/KP propellant assuming a burn rate 0.50 inch per second at 1000 psi with the same pressure exponent of 0.70 (identified as PVC/KP-2) without any seven perforation grains. After several attempts to optimize the performance with this faster burning propellant, and to eliminate the perforated grains, the following charge sizes gave the performance listed in Table 6. It appears that any burn rate between 0.35 and 0.50, would give acceptable performance.

Table 6. Best SPP/Catapult System Performance Data With PVC/KP-2 Propellant

Igniter Charge: 1.3 grams, Type II-A $BKNO_3$ BI-CONVEX (MIL-P-46994) pellets.
Fast Burn Charge: 1.10 gram, 0.100 inch thick PVC/KP-2 strips.
Slow Burn Charge: 5.3 inch long, 0.210 inch ID, 0.700 inch OD (61 grams), PVC/KP-2 grain.

CONDITION	%ILE	SEAT ACCELERATION	SEPARATION VELOCITY	MAXIMUM DRI	STROKE TIME
-	-	G	FPS	-	MILLISECOND
1	3	0	48.8	15.0	121
2	3	4.05	46.4	17.3	131
3	MEAN	0	46.7	12.7	129
4	MEAN	4.05	44.7	17.4	140
5	98	0	45.1	12.4	135
6	98	4.05	43.0	17.5	147

3.6 Task 6 Efforts

Since Concept (2) was selected as the optimum approach and was carried through its preliminary design in the Task 4 efforts, there were no significant work efforts performed under this task.

3.7 Task 7 Efforts

The following efforts in documentation and reporting were provided through the course of this SBIR Phase I program.

3.7.1 Kickoff Meeting - This study effort was initiated in a meeting at Wright Field on 19 May 1998. The planned seven tasks in this study effort were outlined. The information that was available at that time was provided from studies performed under earlier contracts, and from efforts expended in preparation for this SBIR study effort.

3.7.2 Interim Report 1 - The first of two Interim Reports was delivered to the Technical Monitor on 12 June 1998 and could only cover the first four weeks of this SBIR Phase I study effort. This report was a contract delivery item.

3.7.3 Letter Progress Report 1 - The first of three planned Letter Progress Reports was mailed to the Technical Monitor on 10 July 1998. This report covered the period of 13 May 1998 to 3 July 1998.

3.7.4 Interim Report 2 - The second Interim Report was delivered to the Technical Monitor on 7 August 1998 and covered the study efforts performed up to that time. This report was a contract delivery item.

3.7.5 Letter Progress Report 2 - The second Letter Progress Report was mailed to the Technical Monitor on 17 September 1998. It provided the first results from the computer study on the SPP that indicated that the velocity input by the SPP would be in the range of ten to eleven feet per second.

3.7.6 Draft Final Report - This Draft Final Report was prepared under this task work effort.

3.7.7 Final Report - The Final Report will be prepared under this task work effort.

4. PROBLEMS ENCOUNTERED

The major problem anticipated in this study effort was finding a location for the SPP that would be acceptable for use in the different aircraft in which the ACES II escape system was installed. After receiving the J115103-517 SAAA and the Douglas Aircraft Company J115103 Drawing, it was learned that the best and simplest place to locate the SPP was just below the CKU-5B/A Catapult and integrated into the Breech of that unit. Thus, what was considered a major problem was found to have a relatively simple solution.

An unanticipated problem arose after receiving the drawings from UPCo. At that time, we learned that the pressurized area in the CKU-5B/A Catapult was only 0.785 square inch and required catapult pressures well over 5000 psi to provide the desired thrust levels. With these extreme high pressures the propellant burn rate was excessive and would not allow the expected improvement in performance predicted earlier using an appreciably larger pressurized area. As previously noted, the chief propellant research scientist at UPCo, Dr. James Baker, indicated that their PVC/KP propellant, which does not have a break in the burn rate versus pressure curve, could be slowed down to some value close to that which appears to be near optimum for the modified CKU-5B/A Catapult when the SPP is added. It is anticipated that the severity of this problem can be appreciably reduced. The catapult performance that is realized by adding the SPP to the CKU-5B/A will be better than that which would be realized using the current propellant.

5. MILESTONES

The significant milestones in this SBIR Phase I study include the following inputs/accomplishments.

MILESTONE (1).

Determined there is sufficient space below the CKU-5B/A Rocket Catapult to integrate the SPP into its Breech. The most significant accomplishment of this SBIR Phase I study effort.

MILESTONE (2).

Modified the model representing the catapult in the existing Gaussian optimization program to provide the following: represent low/high pressure burn rate functions; represent seven perforation inside burning pellets; allow tabular input of acceleration functions to represent either the SPP input acceleration or any positive Gz acceleration of the seat (or of the sled acceleration in tests); and represent very thin web propellant shavings.

MILESTONE (3).

Optimized the SPP performance for the four combinations of the lightest weight and the heaviest weight ejecting under the positive Z-axis seat accelerations of zero and 4.05G. This gives the velocity at the end of the piston stroke between 10.1 feet per second and 11.0 feet per second.

MILESTONE (4).

Optimized the performance of the modified CKU-5B/A Catapult with the SPP integrated into it, for the four combinations of the lightest weight and the heaviest weight ejecting under the positive Z-axis seat accelerations of zero and 4.05G. This was accomplished using the modified UPCo PVC/KP propellant with a burn rate of 0.35 inch per second at a pressure of 1000 psi (identified as PVC/KP-1), which gave the velocity at the end of the catapult stroke between 42.6 feet per second and 50.4 feet per second with a maximum DRI of 18.0 for the small female at the 4.05G seat acceleration condition. Graphs of the Acceleration input and the resulting DRI curves for these four combinations of eject weight and positive upward aircraft acceleration are included in Appendix B.

MILESTONE (5).

As in Milestone 4, optimized the performance of the modified CKU-5B/A Catapult with the SPP integrated into it using the modified UPCo PVC/KP propellant with a burn rate of 0.50 inch per second at a pressure of 1000 psi (identified as PVC/KP-2). This gives the velocity at the end of the catapult stroke between 43.0 feet per second and 48.8 feet per second, with a maximum DRI of 17.3 for the small female at the 4.05G seat acceleration condition. Graphs of the Acceleration input and the resulting DRI curves for these four combinations of eject weight and positive upward seat acceleration are also included in Appendix B.

6. SPECIAL TEST CONSIDERATIONS

In any future test activities of the CKU-5B/A Catapult with the SPP integrated into it there are some important items which must be considered in planning the tests. Those recognized at this time include the following items.

ITEM (1) - TEST SLED WEIGHT

The weight of the aircraft in which this modified CKU-5B/A Catapult with the SPP integrated into it will be installed are expected to range upward from 18,000 pounds to over 50,000 pounds. Thus, the apparent mass of the cockpit reacting to the SPP and Modified CKU-5B/A downward force levels is expected to be 15,000 pounds or greater. Therefore, it is desirable to have a test sled weight as close to 15,000 pounds as is practical. Because the maximum test ejected weight is around 450 pounds, and during the 1.125 inch piston stroke will have a peak acceleration of around 20G, it is believed that a sled weight of 9,000 pounds or greater is very desirable.

ITEM (2) - TEST DUMMIES

During the first two inches of travel of the SPP modified CKU-5B/A Catapult, the spine of the ejectee is being compressed about two inches such that the effective mass being accelerated is continuously increasing. In addition, the mass of the lower legs of the ejectee will be only minimally, if at all, affected by this initial motion. Thus it is important to have test dummies that represent the seated (with legs extended forward and supported as is true in an aircraft cockpit) human anatomical response to upward accelerations. The Joint Primary Aircraft Training Systems (JPATS) Manikins (modified small and large aerospace dummies from First Technology Safety Systems, Inc. of Plymouth, Michigan) properly seated and supported should be able to meet this requirement.

ITEM (3) - TEST SEAT

Because the Survival Kit used in the ACES II escape system does not provide a perfectly rigid sitting surface, any test seat used for testing the SPP modified CKU-5B/A Catapult should incorporate a standard ACES II Survival Kit. This seat should also have a back cushion/support surface and headrest, which represent that of the ACES II escape system.

7. TEST PROGRAM

The proposed Phase II program includes a limited test program of up to 24 tests. This test effort will be performed in two stages. In the first stage, only the SPP would be tested to obtain sufficient data to permit definition of the correct amount of the fast burning Alliant Bullseye pistol powder and of the slower burning Alliant Reloder 19 rifle powder that would give the desired seat velocity of ten to eleven feet per second at the end of its stroke. Two tests, first of the small female and then of the large male, would be performed under zero seat upward acceleration (1G Earth gravity). A second set of tests would then be performed using the small female and the large male dummies under zero Earth gravity acceleration (horizontal test stand orientation) with the same amounts of the fast burning Bullseye powder and of the slower burning Reloder 19 rifle powder.

Based on the results of these four tests, computer runs would be made to seek new weights of the Bullseye and Reloder 19 powders that would give the desired ten to eleven feet per second end velocity. A second set of four tests would then be performed using the small female

and the large male dummies under the same zero Gz seat acceleration (1G Earth gravity) and the zero G Earth gravity acceleration using the newly determined amounts of the Bullseye and Reloder 19 powders.

Based on the results of this second set of four tests, the amounts of the Bullseye and Reloder 19 powders would be set and used in subsequent testing. The results of these tests will be used to upgrade the Bullseye and Reloder 19 powder characteristics used as input data to allow an improved computer prediction of the SPP performance when initiated under a 4.05G upward seat acceleration.

In the second stage of tests, the completely modified CKU-5B/A Catapult with the SPP integrated into it will be tested under the above zero seat upward acceleration (1G Earth gravity) and the zero G Earth gravity acceleration conditions with the small female and the large male dummies in a similar sequence as in the earlier series of the first stage tests. Two series of four tests each are planned that would be performed at the LME facility. Modifications to the propellant charges in the CKU-5B/A Catapult would be made as deemed appropriate based on the results of all earlier zero seat and zero G Earth gravity acceleration tests.

After final adjustments to all the powder charges and propellant charges have been made, four final tests would be performed. Although the proposed Phase II program costs prohibit the use of the Hurricane Mesa test track, if any way can be found at least two of the last four tests would be performed at that test site at 4.05Gz seat acceleration condition. In any event, the performance under this 4.05 Gz seat acceleration condition by means of computer simulation will be constantly considered in all powder and propellant charge modifications both in the SPP and the SPP/Catapult system testing.

8. CONCLUSIONS AND RECOMMENDATIONS

It is concluded that the performance of the CKU-5B/A Catapult can be greatly improved through integration of the SPP into it. The following four specific conclusions were reached:

1. The addition of the SPP to the CKU-5B/A Rocket Catapult will significantly reduce the injury potential to any pilot in the USAF total pilot population, especially to the small female, during any ejection under a positive upward seat acceleration up to 4.05G (corresponding to an acceleration level of 4.83G in the CKU-5B/A Catapult tests reported in the report AL-TR-1991-0111).

2. The SPP can be incorporated into the ACES-II Escape System with no modification to the aircraft cockpit and only minor changes to the J115103-511 and -519 Seat Adjustment Actuator Assemblies in the B-1 and F-15M aircraft. Also, there will be no changes to the J115103-513, -515, and -517 Seat Adjustment Actuator Assemblies in the F/TF-15, the A-10, and the F-16A/B aircraft.

3. The SBIR Phase II test program will provide sufficient data to warrant a full development program with sufficient time and tests to truly optimize the propellants used in the CKU-

5B/A Catapult Cartridge. These tests will also optimize and demonstrate the performance of the SPP modified CKU-5B/A Catapult.

4. In conclusion, these minor changes to the CKU-5B/A Catapult would require a delta qualification test program before the SPP modified CKU-5B/A Rocket Catapult could be introduced into service use.

We recommend the following:

1. The Air Force should expedite not only the SBIR Phase II test program but also a full scale development program so the benefits expected from the introduction of this concept into service use is not delayed further.

2. It is highly recommended that the Air Force move quickly to provide spinal preloading to ejecting pilots. It has been years since Air Force personnel first recognized the potential of spinal preloading in escape system catapults to reduce the probability of spinal injury in an ejection. Ten years ago tests on the CKU-5B/A Catapult under positive Gz conditions clearly demonstrated the severe injury potential that would result from an ejection under such positive Gz conditions. Several years have passed since the Air Force conducted drop tower tests with live subjects to demonstrate the potential of spinal preloading to greatly reduce the spinal injury potential in any ejection.

3. We recommend that the Air Force continue to lead the way in applying the Spinal Preload Piston to other escape systems, such as the Navy Aircrew Common Ejection Seat (NACES), since this should positively reduce the incidence of back injuries throughout the armed forces.

APPENDIX A

Drawings of the Spinal Preload Piston Integrated into the Breech of the CKU-5B/A Catapult

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED
–	RELEASE		

CAD MAINTAINED. CHANGES SHALL BE INCORPORATED BY THE DESIGN ACTIVITY

NOTES:

4. LIGHTLY LUBRICATE O-RING, FIND NO. 19, WITH DAMPING FLUID, FIND NO. 21, PRIOR TO ASSEMBLY.
5. APPLY A LIGHT UNIFORM COATING OF ADHESIVE, FIND NO. 20, TO ONE SIDE OF ABSORBER, FIND NO. 8, PRIOR TO ASSEMBLY.
6. APPLY A COATING OF THREAD LOCKING COMPOUND, FIND NO. 23, TO THREADS OF SHOULDER SCREWS, FIND NO. 13, AND FHCS, FIND NO. 12. REMOVE EXCESS THREAD LOCKING COMPOUND.
7. APPLY A LIGHT COATING OF LUBRICANT, FIND NO. 22, TO O-RINGS, FIND NO. 14 THRU NO. 18, AND TO BALL BEARINGS, FIND NO. 10, PRIOR TO ASSEMBLY.

QUANTITY REQUIRED PER DASH NO	SYM	NOMENCLATURE	CODE IDENT / IDENTIFYING NO	MATERIAL / SPECIFICATION	UNIT WT / ZONE	FIND NO
AR		COMPOUND, THREAD LOCKING	TYPE ?, GRADE N	MIL-S-46163	C/5	23
AR		LUBRICANT, GREASE	5184334		C/5	22
AR		LUBRICANT		DAMPING FLUID, 60,000 Cst (DC-200), V V-D-1078	C/5	21
AR		ADHESIVE, EPOXY		MIL-A-52194	C/5	20
1		O-RING		MS28775-011 MIL-G-5514F	B/2	19
1		O-RING		AS568A-031	C/2	18
1		O-RING		AS568A-029	C/3	17
1		O-RING		MS28775-025 MIL-G-5514F	C/2	16
1		O-RING		MS28775-020 MIL-G-5514F	C/3	15
1		O-RING		MS28775-016 MIL-G-5514F	C/2	14
4		SHOULDER SCREW		5/16 X 1-1/4 HOLO-KROME	B/6	13
2		FHCS		MATERIAL SPECS	B/6	12
2		SHEAR PIN		MATERIAL SPECS	C/3	11
6		BALL BEARING		3/16" DIAMETER	C/4	10
1		HOUSING, FIRING	11041406-01	STEEL BAR, TYPE 1215 ASTM A 108, COLD FINISHED	B/4	9
4		ABSORBER	11041405-01	ALUMINUM (SOFT)	C/6	8
1		BALL RELEASE	11041404-01	2024-T4 ALUMINUM QQ-A-250/4	C/5	7
1		BALL LOCK HOUSING	11041403-01	2024-T4 ALUMINUM QQ-A-250/4	C/5	6
1		BREECH MOUNT	11041402-01	2024-T4 ALUMINUM QQ-A-250/4	C/6	5
1		BREECH	11041401-01	2024-T4 ALUMINUM QQ-A-250/4	C/6	4
						3
						2
X		SPINAL PRELOADING PISTON ASSEMBLY	-01		2	1

NOTES UNLESS OTHERWISE SPECIFIED

1. DIMENSIONS IN INCHES
2. INTERPRET DRAWING PER MIL-STD-100E
3. TOLERANCES DECIMALS XX± .01 XXX± .005 ANGLES ± 30' FRACTIONS ±

CONTRACT NUMBER F41624-98-C-5049

U.S. AIR FORCE

TITLE SPINAL PRELOADING PISTON ASSEMBLY

SIZE D | CAGE 98750 | DRAWING NO. 11041400

SCALE 1/1 | SHEET 1 OF 2

APPLICATION

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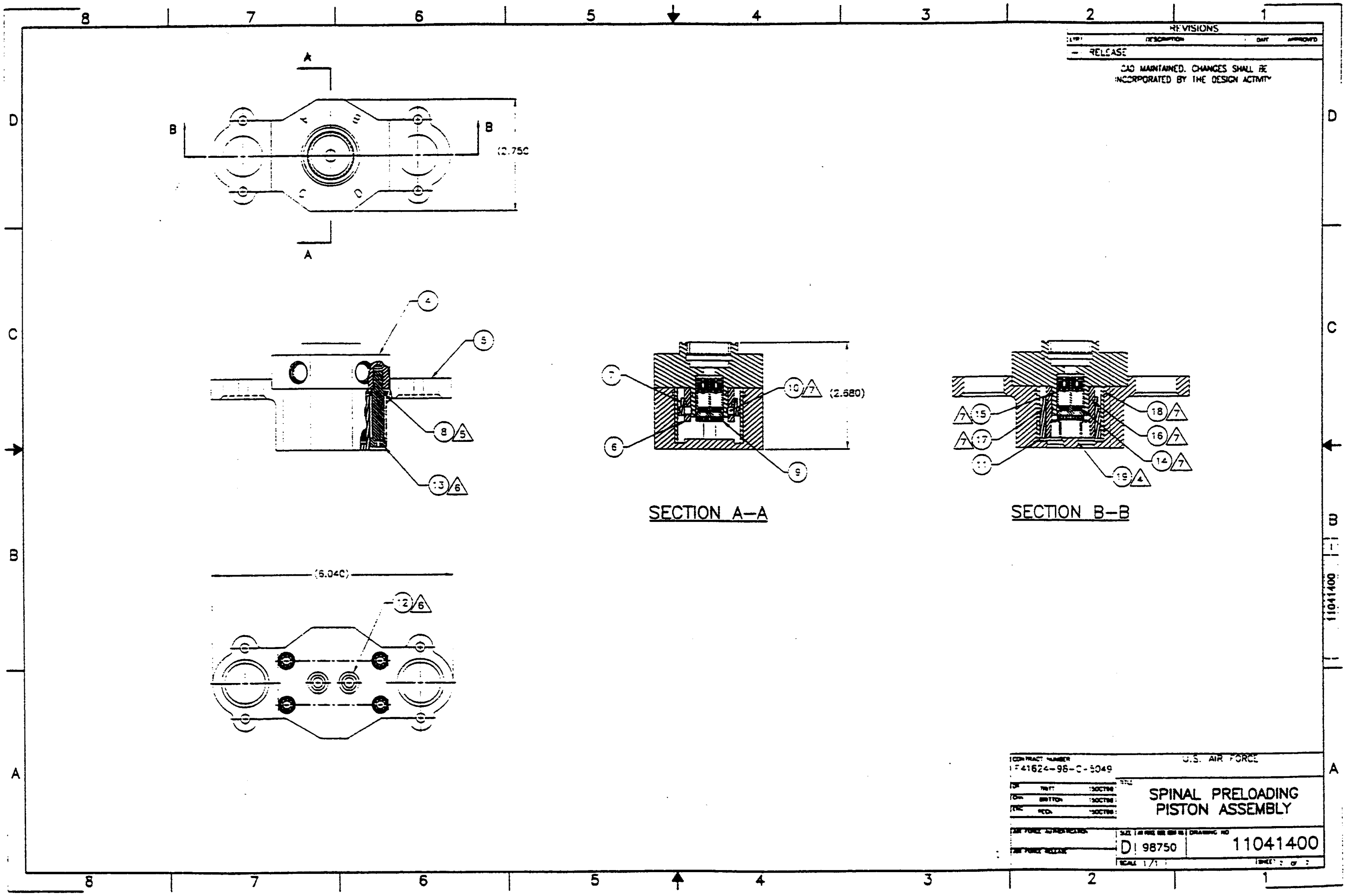
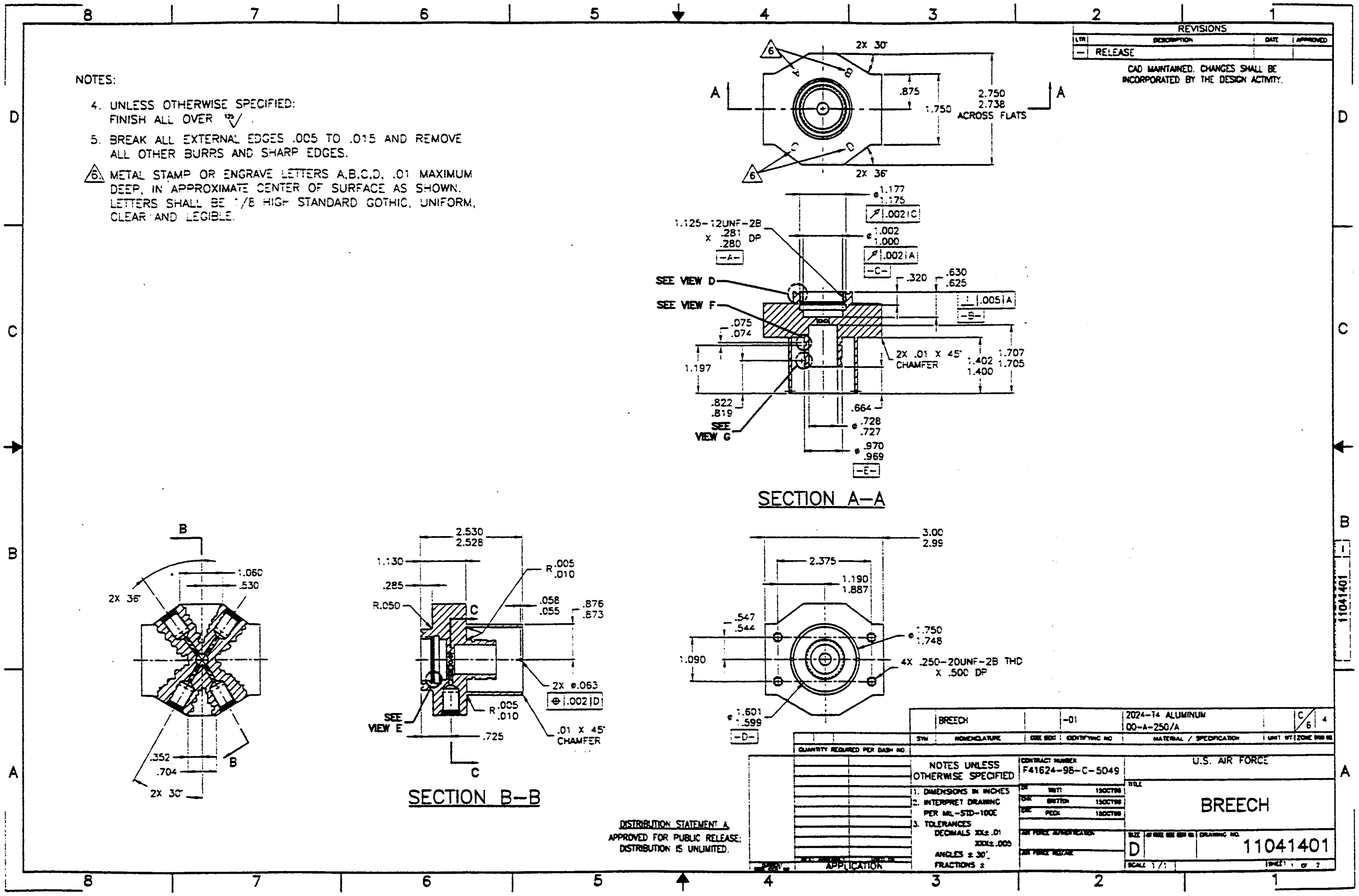
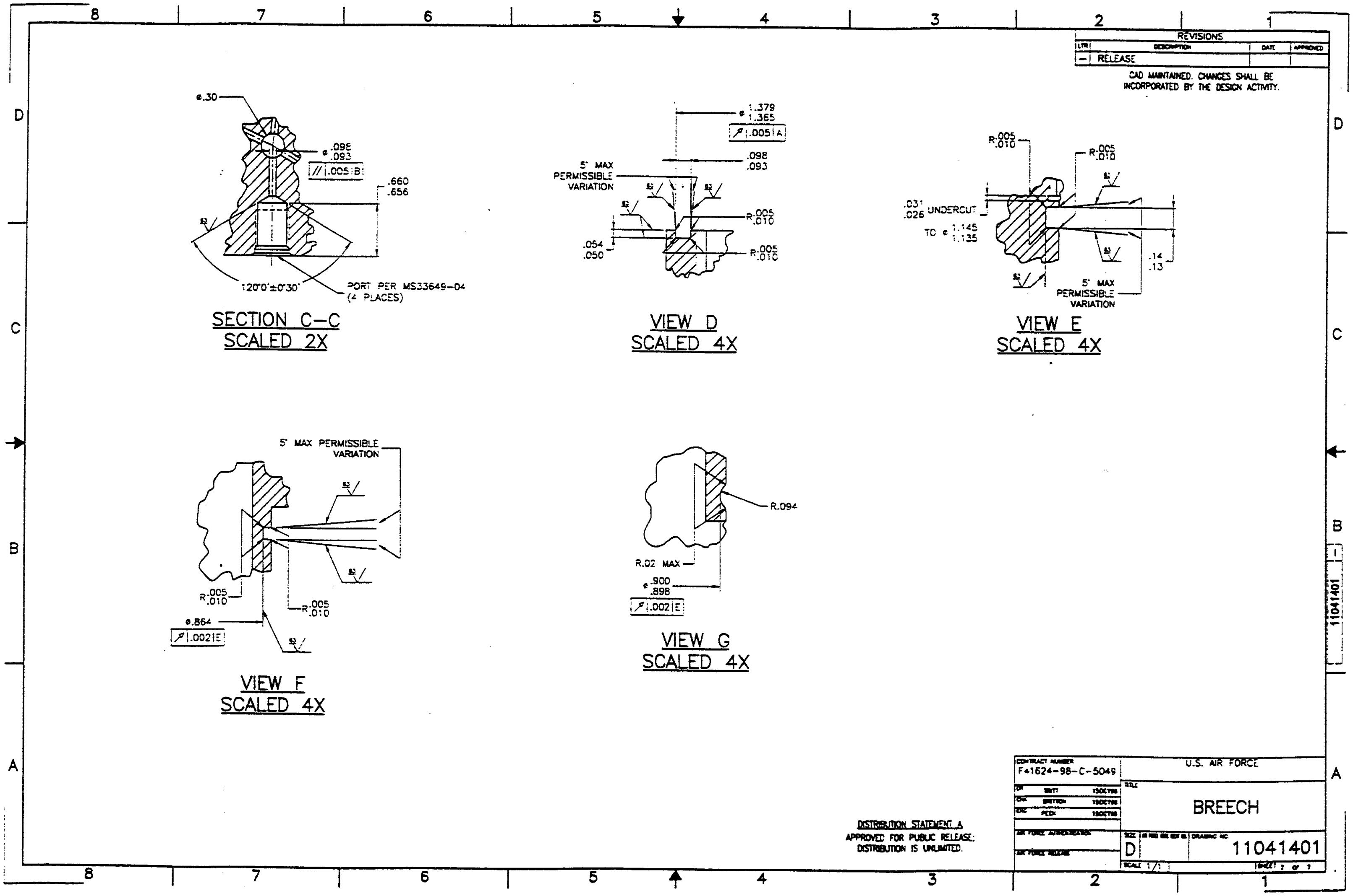
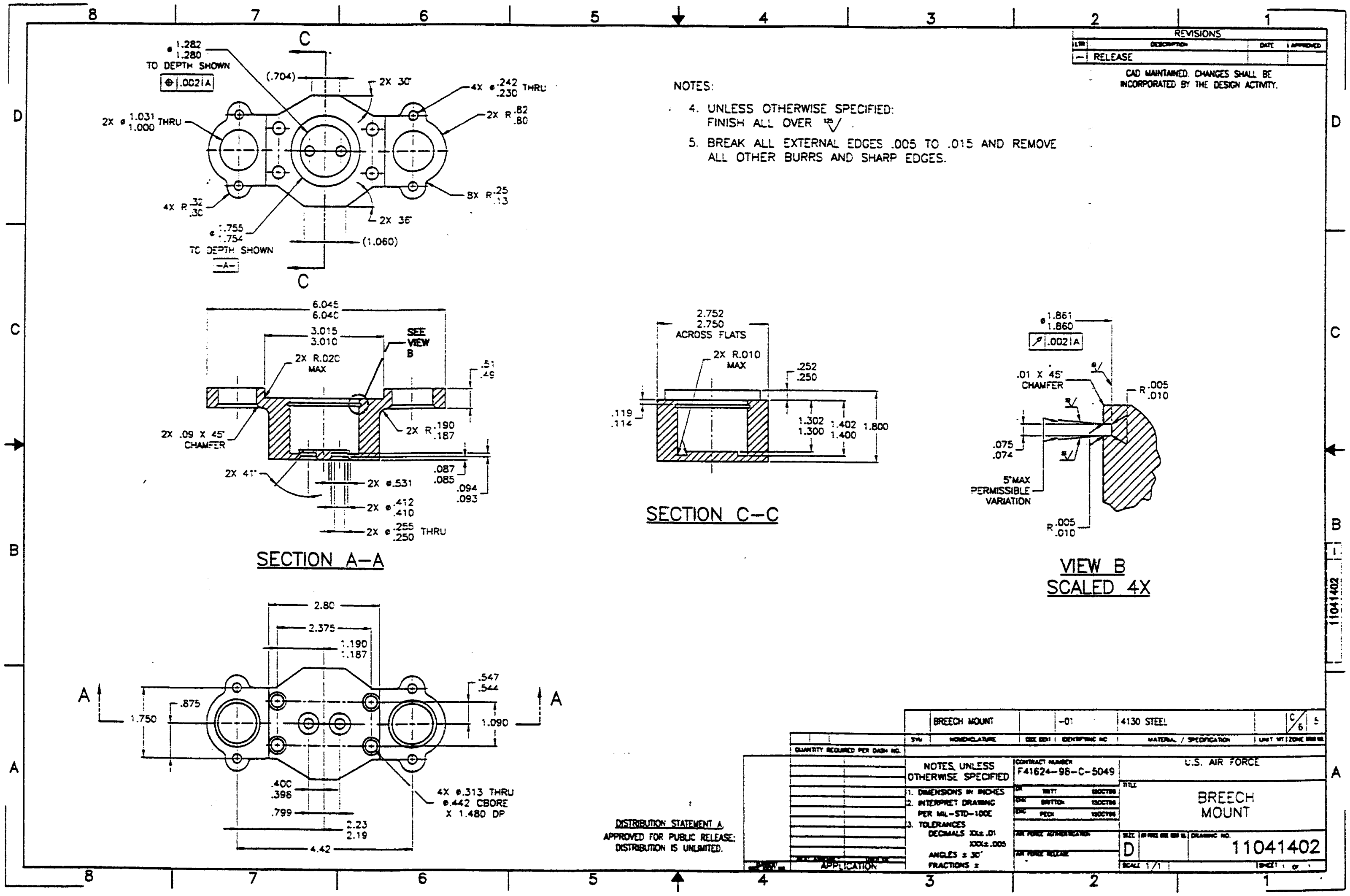

REVISIONS
- RELEASE
CAD MAINTAINED. CHANGES SHALL BE INCORPORATED BY THE DESIGN ACTIVITY
(2.750)
(2.680)
(6.040)
SECTION A–A
SECTION B–B
CONTRACT NUMBER
F41624-96-C-5049
U.S. AIR FORCE
SPINAL PRELOADING
PISTON ASSEMBLY
D 98750
11041400
11041400

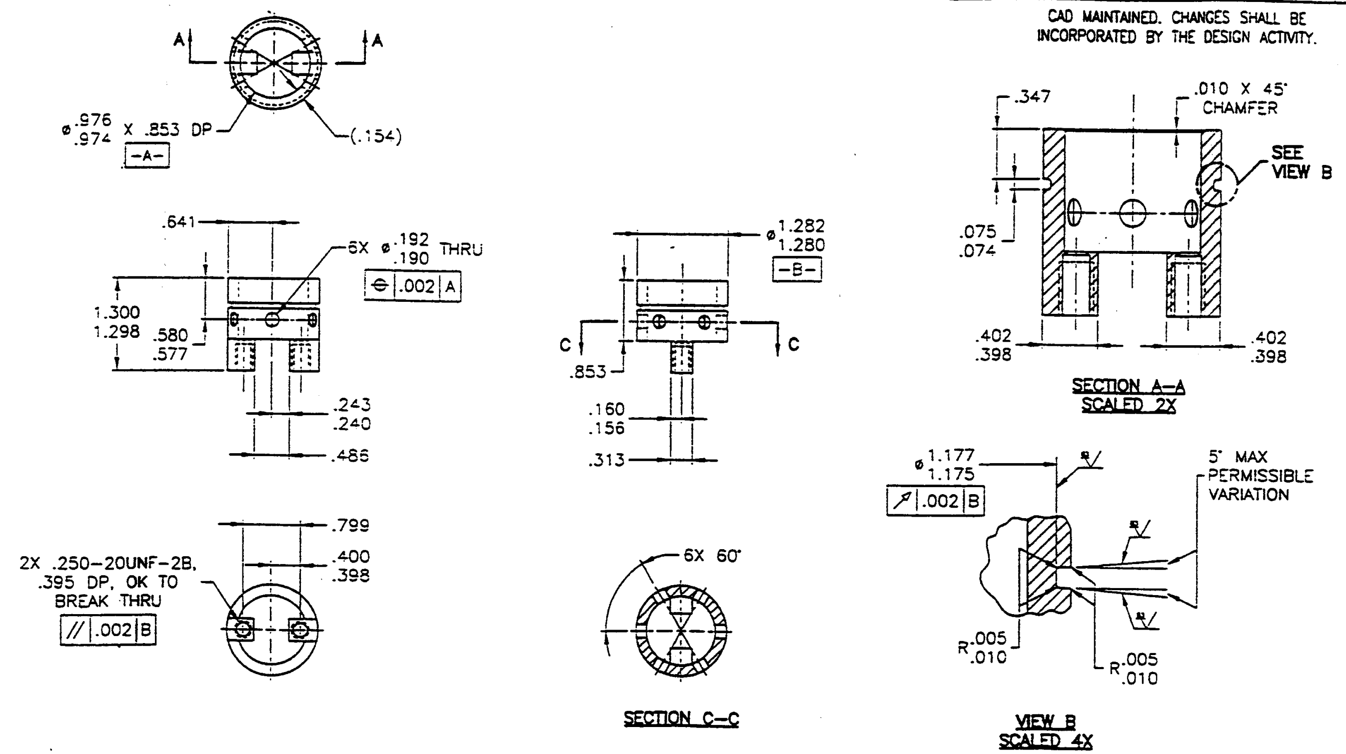

REVISIONS
LTR
DESCRIPTION
DATE
APPROVED
— RELEASE
CAD MAINTAINED. CHANGES SHALL BE INCORPORATED BY THE DESIGN ACTIVITY.
NOTES:
4. UNLESS OTHERWISE SPECIFIED: FINISH ALL OVER
5. BREAK ALL EXTERNAL EDGES .005 TO .015 AND REMOVE ALL OTHER BURRS AND SHARP EDGES.
6 METAL STAMP OR ENGRAVE LETTERS A,B,C,D, .01 MAXIMUM DEEP, IN APPROXIMATE CENTER OF SURFACE AS SHOWN. LETTERS SHALL BE 1/8 HIGH STANDARD GOTHIC, UNIFORM, CLEAR AND LEGIBLE.
2X 30°
2X 36°
.875
1.750
2.750
2.738
ACROSS FLATS
1.177
1.175
.002 C
1.125-12UNF-2B
X .281 .280 DP
-A-
1.002
1.000
.002 A
-C-
.320
.630
.625
.005 A
-B-
SEE VIEW D
SEE VIEW F
.075
.074
1.197
2X .01 X 45° CHAMFER
1.402
1.400
1.707
1.705
.822
.819
SEE VIEW G
.664
.728
.727
.970
.969
-E-
SECTION A-A
1.060
.530
2X 36°
.352
.704
2X 30°
2.530
2.528
1.130
.285
R.050
R .005 .010
.058
.055
.876
.873
2X ø.063
.002 D
.01 X 45° CHAMFER
SEE VIEW E
.725
SECTION B-B
3.00
2.99
2.375
1.190
1.887
.547
.544
1.090
1.750
1.748
4X .250-20UNF-2B THD X .500 DP
1.601
1.599
-D-
DISTRIBUTION STATEMENT A
APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED.
BREECH
-01
2024-T4 ALUMINUM
QQ-A-250/A
NOMENCLATURE
MATERIAL / SPECIFICATION
QUANTITY REQUIRED PER DASH NO
NOTES UNLESS OTHERWISE SPECIFIED
1. DIMENSIONS IN INCHES
2. INTERPRET DRAWING PER MIL-STD-100E
3. TOLERANCES DECIMALS XX± .01 XXX± .005 ANGLES ± 30'. FRACTIONS ±
CONTRACT NUMBER
F41624-98-C-5049
U.S. AIR FORCE
BREECH
D
11041401
SCALE 1/1
APPLICATION


REVISIONS
LTR | DESCRIPTION | DATE | APPROVED
– RELEASE
CAD MAINTAINED. CHANGES SHALL BE INCORPORATED BY THE DESIGN ACTIVITY.
SECTION C–C
SCALED 2X
PORT PER MS33649-04
(4 PLACES)
120°0'±0°30'
.660
.656
VIEW D
SCALED 4X
5° MAX
PERMISSIBLE
VARIATION
VIEW E
SCALED 4X
.031
.026
UNDERCUT
.14
.13
VIEW F
SCALED 4X
5° MAX PERMISSIBLE
VARIATION
VIEW G
SCALED 4X
R.094
R.02 MAX
DISTRIBUTION STATEMENT A
APPROVED FOR PUBLIC RELEASE;
DISTRIBUTION IS UNLIMITED.
CONTRACT NUMBER
F41624-98-C-5049
U.S. AIR FORCE
BREECH
D
11041401
SCALE 1/1
SHEET 2 OF 2


NOTES:
4. UNLESS OTHERWISE SPECIFIED: FINISH ALL OVER
5. BREAK ALL EXTERNAL EDGES .005 TO .015 AND REMOVE ALL OTHER BURRS AND SHARP EDGES.
REVISIONS
RELEASE
CAD MAINTAINED. CHANGES SHALL BE INCORPORATED BY THE DESIGN ACTIVITY.
SECTION A–A
SECTION C–C
VIEW B
SCALED 4X
DISTRIBUTION STATEMENT A.
APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED.
BREECH MOUNT
-01
4130 STEEL
NOTES, UNLESS OTHERWISE SPECIFIED
1. DIMENSIONS IN INCHES
2. INTERPRET DRAWING PER MIL-STD-100E
3. TOLERANCES DECIMALS XX± .01 XXX± .005 ANGLES ± 30' FRACTIONS ±
CONTRACT NUMBER
F41624-98-C-5049
U.S. AIR FORCE
BREECH MOUNT
D
11041402
SCALE 1/1
APPLICATION

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED
—	RELEASE		

CAD MAINTAINED. CHANGES SHALL BE INCORPORATED BY THE DESIGN ACTIVITY.



SYM	NOMENCLATURE	CODE IDENT	IDENTIFYING NO.	MATERIAL / SPECIFICATION	UNIT WT	ZONE	FIND NO.
	BALL LOCK HOUSING		-01	2024-T4 ALUMINUM QQ-A-250/4		C/5	6

QUANTITY REQUIRED PER DASH NO.

NOTES UNLESS OTHERWISE SPECIFIED
1. DIMENSIONS IN INCHES
2. INTERPRET DRAWING PER MIL-STD-100E
3. TOLERANCES
DECIMALS XX±.010
XXX±.005
ANGLES ± 30'
FRACTIONS ±

CONTRACT NUMBER F41624-98-C-5049

DR	TRITT	15OCT98
CHK	BRITTON	15OCT98
ENG	PECK	15OCT98

AIR FORCE AUTHENTICATION

AIR FORCE RELEASE

U.S. AIR FORCE

TITLE BALL LOCK HOUSING

SIZE C | AIR FORCE CODE IDENT NO. | DRAWING NO. 11041403

SCALE 1/1 | SHEET 1 OF 1

CURRENT CODE IDENT NO | NEXT ASSEMBLY | USED ON
APPLICATION

11041403 | —

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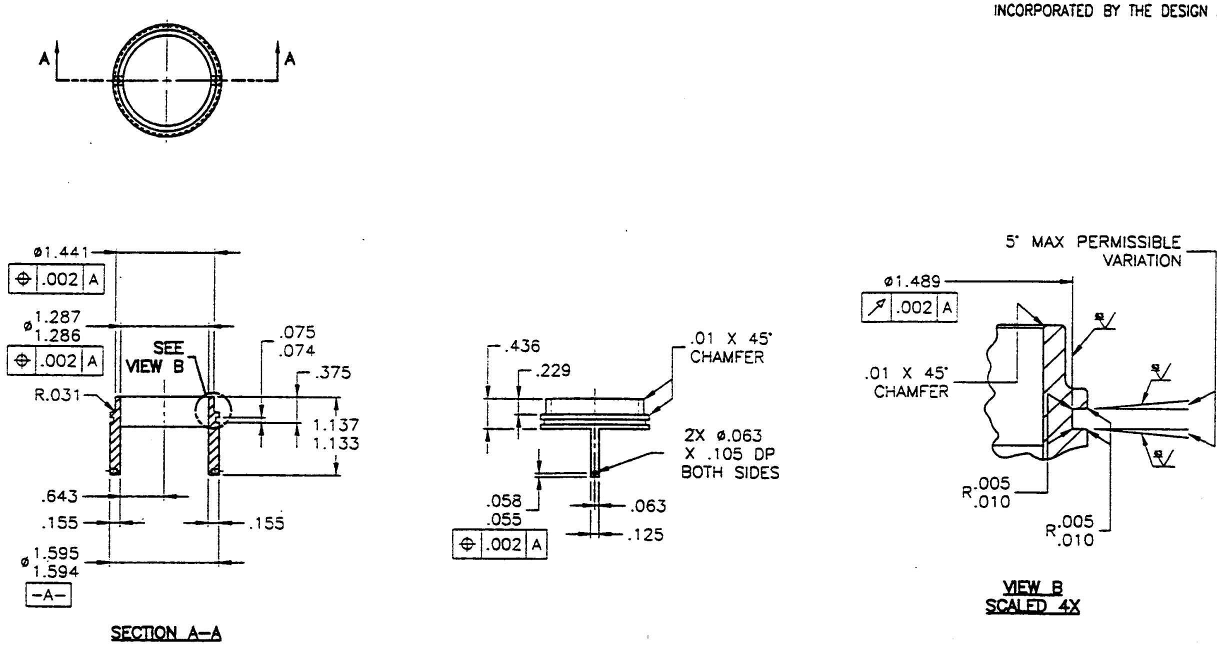

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED
—	RELEASE		

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SYM	NOMENCLATURE	CODE IDENT	IDENTIFYING NO.	MATERIAL / SPECIFICATION	UNIT WT	ZONE	FIND NO.
	BALL RELEASE		-01	2024-T4 ALUMINUM QQ-A-250/4		C/5	7

QUANTITY REQUIRED PER DASH NO.

NOTES UNLESS OTHERWISE SPECIFIED
1. DIMENSIONS IN INCHES
2. INTERPRET DRAWING PER MIL-STD-100E
3. TOLERANCES
DECIMALS XX±.010 XXX±.005
ANGLES ± 30'
FRACTIONS ±

CONTRACT NUMBER F41624-98-C-5049

DR	TRITT	15OCT98
CHK	BRITTON	15OCT98
ENG	PECK	15OCT98

AIR FORCE AUTHENTICATION
AIR FORCE RELEASE

U.S. AIR FORCE

TITLE BALL RELEASE

SIZE C | AIR FORCE CODE IDENT NO. | DRAWING NO. 11041404

SCALE 1/1 | SHEET 1 OF 1

CURRENT CODE IDENT NO | NEXT ASSEMBLY | USED ON
APPLICATION

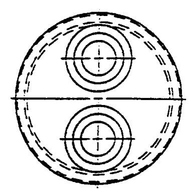
11041404 | —

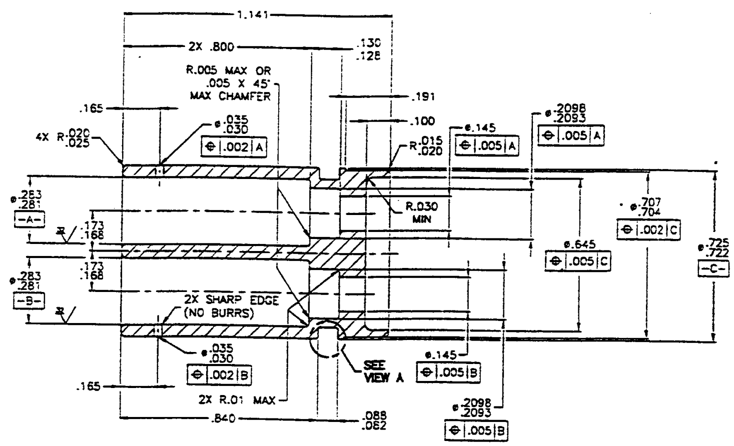
REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED
–	RELEASE		–

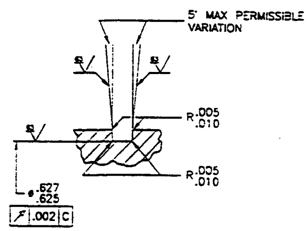
CAD MAINTAINED. CHANGES SHALL BE INCORPORATED BY THE DESIGN ACTIVITY.

NOTES:

4. MATERIAL: STEEL BAR, CARBON, TYPE 1213, 1214, 1215, 12L14 OR 12L15 IN ACCORDANCE WITH ASTM A 108, COLD FINISHED.
5. UNLESS OTHERWISE SPECIFIED, 125 ALL OVER.
6. BREAK ALL SHARP EDGES .005 TO .015R, EXCEPT AS SHOWN.
7. CADMIUM PLATE IN ACCORDANCE WITH QQ-P-416, TYPE II, CLASS 3.
8. DIMENSIONAL LIMITS APPLY AFTER PLATING.
9. MATERIAL HARDNESS SHALL BE RB 70 MINIMUM.







VIEW A

DISTRIBUTION STATEMENT A
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NOTES UNLESS OTHERWISE SPECIFIED
1. DIMENSIONS IN INCHES
2. INTERPRET DRAWING PER MIL-STD-100E
3. TOLERANCES
DECIMALS XX± .01
XXX± .005
ANGLES ± 30'
FRACTIONS ±

CONTRACT NUMBER F41624-98-C-5049

U.S. AIR FORCE

SMALL HOUSING, FIRING PIN

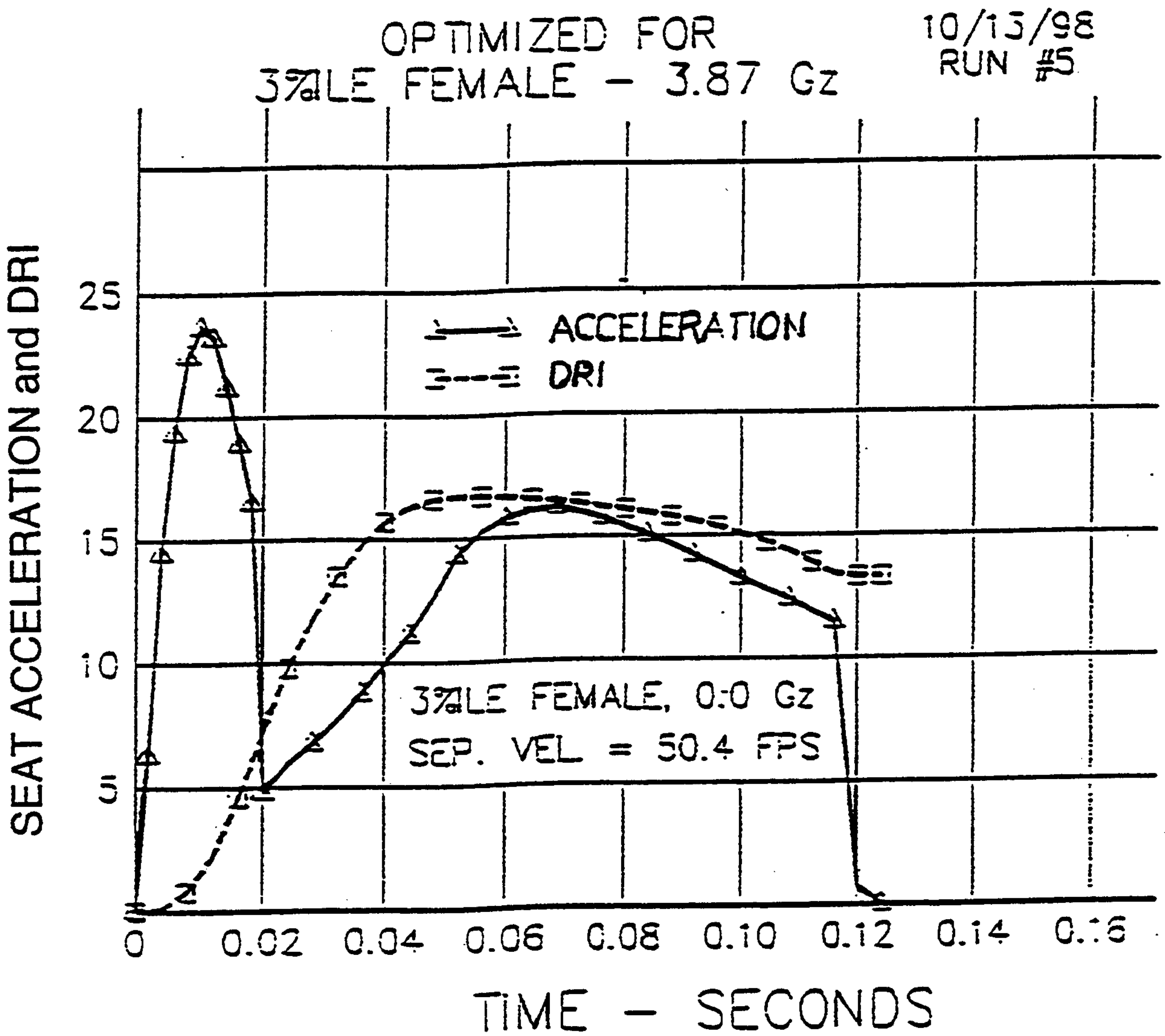
SIZE D | CAGE 98750 | DRAWING NO. 11041408

SCALE 5/1 | SHEET 1 OF 1

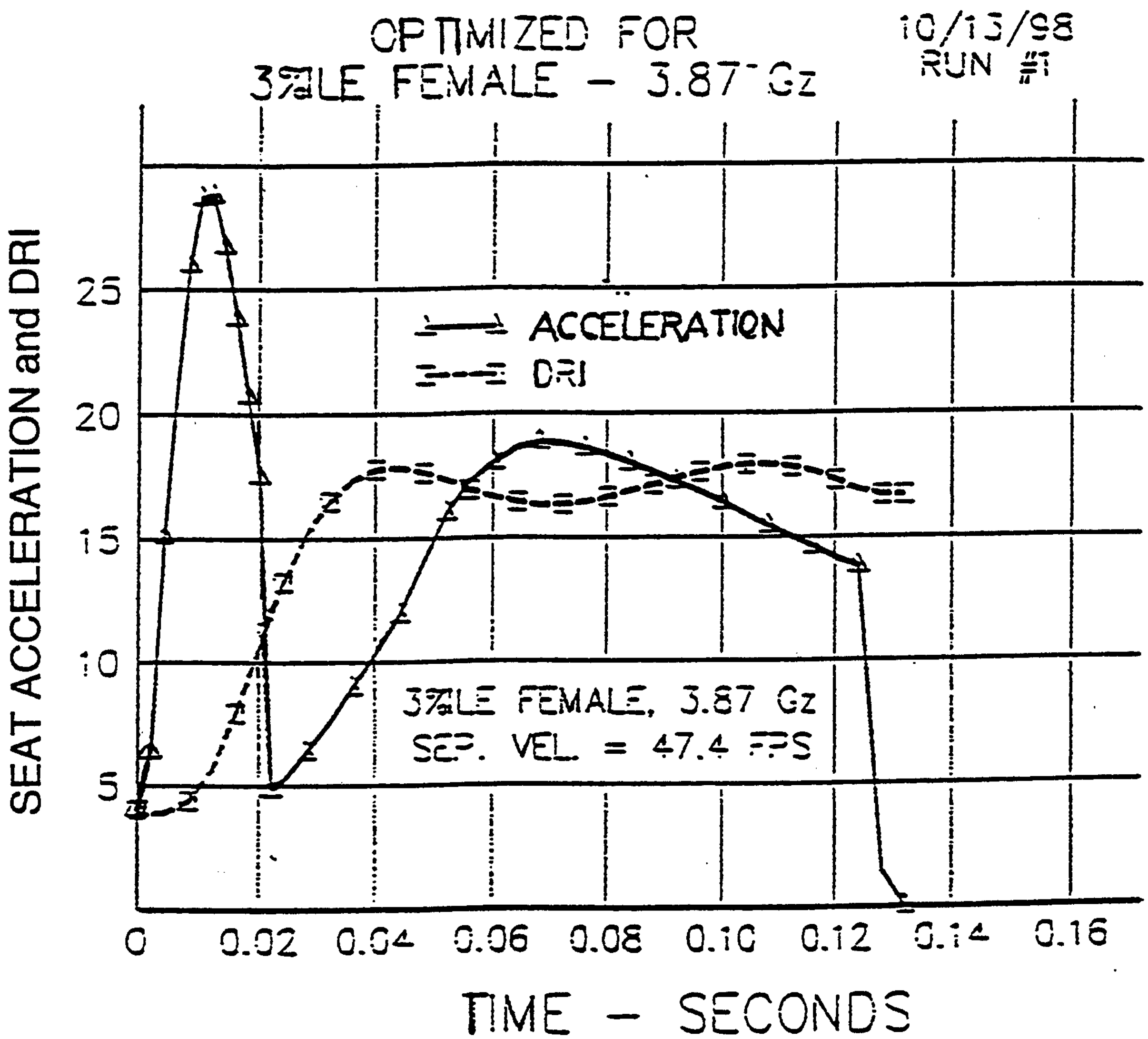
APPLICATION

APPENDIX B

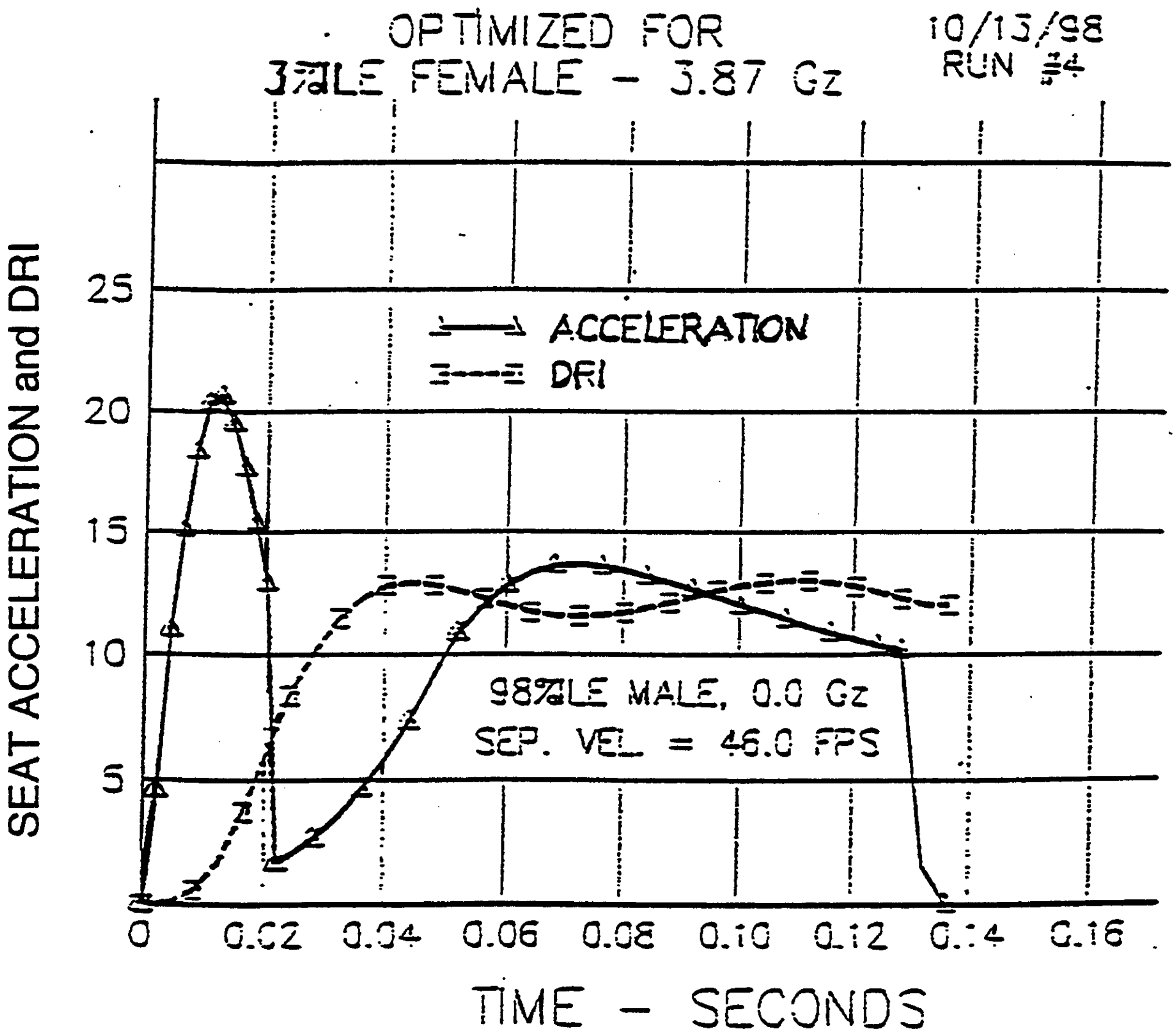
Seat acceleration and DRI for the Optimized Charges of the PVC/KP-1 and PVC/KP-2 Propellants



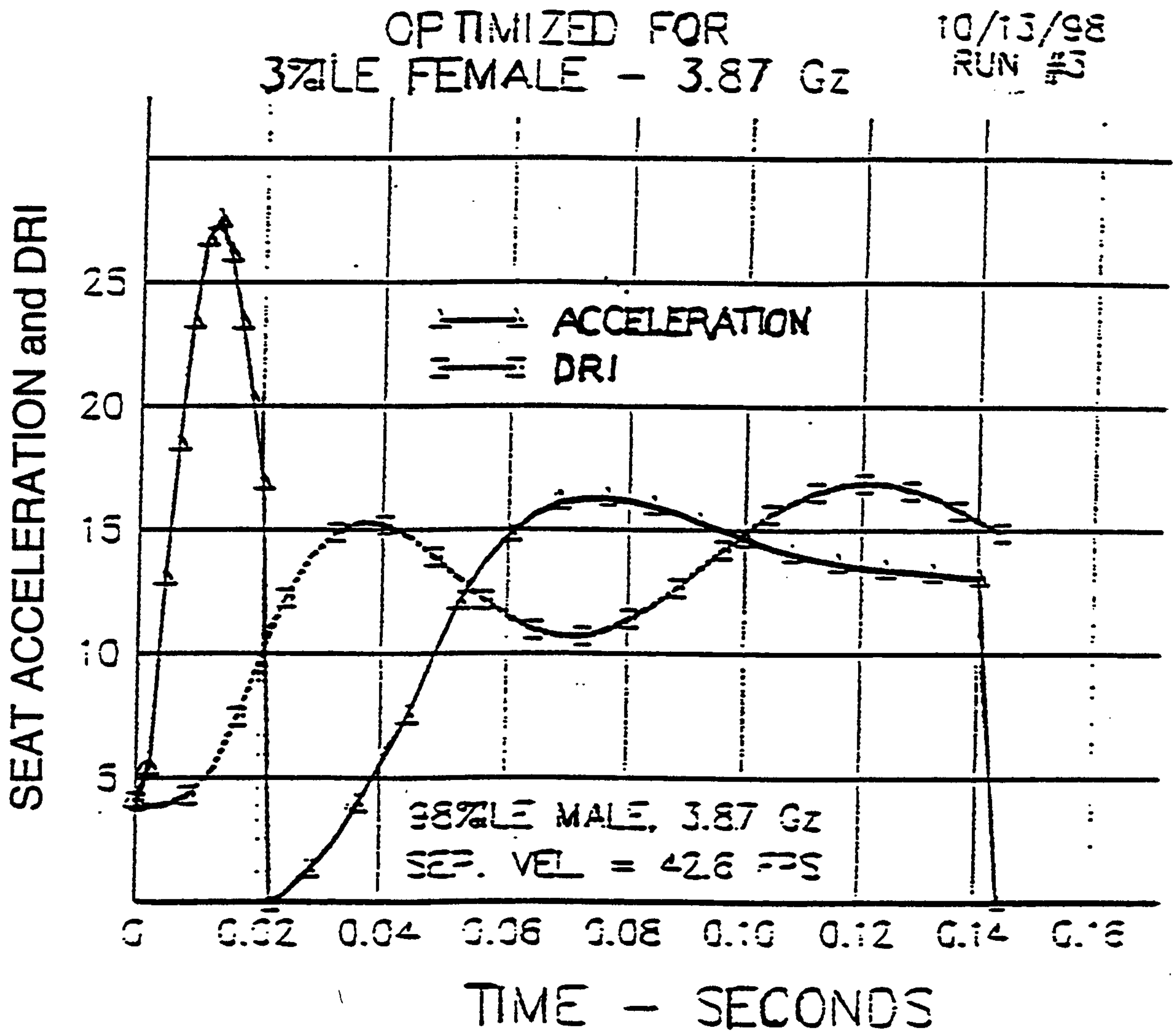
OPTIMIZED FOR
3%ILE FEMALE - 3.87 Gz
10/13/98
RUN #5
ACCELERATION
DRI
3%ILE FEMALE, 0:0 Gz
SEP. VEL = 50.4 FPS
SEAT ACCELERATION and DRI
25
20
15
10
5
0
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
TIME - SECONDS



OPTIMIZED FOR
3%LE FEMALE - 3.87 Gz
10/13/98
RUN #1
ACCELERATION
DRI
3%LE FEMALE, 3.87 Gz
SEP. VEL. = 47.4 FPS
SEAT ACCELERATION and DRI
5
10
15
20
25
0
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
TIME - SECONDS



OPTIMIZED FOR
3%ILE FEMALE - 3.87 Gz
10/13/98
RUN #4
ACCELERATION
DRI
98%ILE MALE, 0.0 Gz
SEP. VEL = 46.0 FPS
SEAT ACCELERATION and DRI
25
20
15
10
5
0
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
TIME - SECONDS



OPTIMIZED FOR
3%ILE FEMALE - 3.87 Gz
10/13/98
RUN #3
ACCELERATION
DRI
98%ILE MALE, 3.87 Gz
SEP. VEL = 42.6 FPS
SEAT ACCELERATION and DRI
25
20
15
10
5
0
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
TIME - SECONDS